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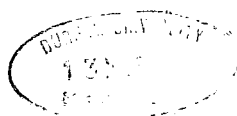
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AN INVESTIGATION INTO REPRODUCTIVE  
EFFORT IN TWO SUCCESSIONAL STAGES  
USING REGRESSION TECHNIQUES

A M WILSON

Thesis submitted for  
M.Sc. Advanced course  
in Ecology.  
University of Durham  
October 1980



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## 1. INTRODUCTION

Life histories are partly the result of selection for the optimal allocation of resources to maintenance, growth and reproduction in a particular environment. The manner in which natural selection acts to partition the available resources has been considered from numerous theoretical viewpoints (e.g. Gadgil and Bossert 1970, Wilbur et al 1974) and has given rise to much recent research (e.g. Gadgil and Solbrig 1972, Harper and Ogden 1970, Stearns 1977). A basic tenet of this research work is that there is a 'cost' associated with reproduction (see Stearns 1976).

Harper (1967) suggested that colonising species of plants would have higher reproductive efforts (R.E's) than plants of mature habitats. The theory of r- and K- selection as developed by MacArthur (1962), Cody (1966), MacArthur and Wilson (1967), Gadgil and Bossert (1970) and others predicts that in situations where density-dependent mortality is low r-selection will favour genotypes with a high rate of increase. The degree of environmental uncertainty has also been found to be a significant factor in selection for life history strategies (e.g. Southwood et al 1974, Wilbur et al 1974). Gadgil and Solbrig (1972) correlated highly disturbed or uncertain environments with r- selection and less uncertain environments with K- selection. They suggest that r- selected genotypes may have a greater reproductive effort and shorter life span than K- selected genotypes. Grime (e.g. 1974, 1977) has extended and developed the theory of r- and K- selection to suggest that there may be three main strategies. Plants may be adapted to competition, stress or disturbance with a range of possible options between these extremes.

The majority of previous research on resource allocation has tended to concentrate on one species, either by examining single



species populations from various sites (Gadgil and Solbrig 1972, Bradbury and Hofstra 1975, Hickman 1975, Holler and Abrahamson 1977, Roos and Quinn 1977, Raynal 1979) or by assessing the effect of changing one or more environmental variables on the allocation patterns (Harper and Ogden 1970, Ogden 1974, Hawthorn and Cavers 1978). Other workers have studied allocation patterns in a range of closely related species and attributed variations to differences in life strategy. (Gaines et al 1974, Hickman 1977, Pitelka 1977 Bell et al 1979, Bostock and Benton 1979, Primack 1979).

There has been relatively little work on allocation patterns in a range of species over a succession in the field (Newell and Tramer 1978, Abrahamson 1979, Stewart 1979) ("Succession" has been defined by Connell and Slatyer (1977) as "the changes observed in an ecological community following a perturbation that opens up a relatively large space") Nevertheless these studies have tended to confirm the r- and K- selection theory, the populations in the earlier successional habitats usually having higher reproductive efforts. Stewart (1979) found that higher population R.E's were primarily a result of greater numbers of flowering individuals rather than higher individual R.E. The suggestion that the number of individuals which flower in a population can vary because of changing conditions is supported by Van Andel and Vera (1977). In the perennial Chamaenerion angustifolium the numbers of flowering individuals were decreased by reducing mineral supply.

Stewart's (1979) work left several questions about the mechanism underlying variation in R.E. unanswered. He suggests that the observed variation in R.E. is environmentally rather than genetically controlled but has no empirical evidence. Whilst in some cases variations in resource allocation have been found to be genetically determined e.g. by Gadgil and Solbrig (1972), Abrahamson and Gadgil (1973),

others have shown them to be environmentally cued, plastic responses eg. Hickman (1975), Abrahamson and Hershey (1977), Roos and Quinn (1977).

The variation in the number of flowering individuals in Stewart's work prompted queries concerning the mechanisms which determine the decision to flower. In particular the possibility arose that plant size affects the probability of flowering. The method of analysis which is usually adopted in field resource allocation studies, ie. a random sample of individuals taken from a population at one specified time, makes investigation of this mechanism impossible. A method of following individual plants throughout the season is required. Such a method would not only facilitate investigation of the mechanisms determining the decision to flower, but also render the analysis of changes in reproductive allocation over the growing season statistically more rigorous.

In weight determinations of plants in the field, regression techniques have been used in order to avoid destroying the plants under observation. The method works by setting up relationships linking morphological measurements of the plant and plant weight. Hence the plants can be measured several times as they grow to provide estimates of their weight at intervals of time. Goodall (1945) was one of the first to make use of this method to assess changes in weight of the organs of tomato plants. Whittaker and Woodwell (1968) used regression relationships in their analysis of weight and production of shrubs and trees, advocating parabolic volume as the best. Hutchings (1975) used height  $\times$  diameter<sup>2</sup> to determine weight of Mercurialis perennis but as far as is known only one previous study (Werner 1975) has used the method for a plant with a rosette growth form (Dipsacus folliculorum).

In this study it was hoped that by using a regression technique, some of the problems encountered in previous work could be avoided and some of the questions which were raised, answered.



## 2. OUTLINE OF MAIN METHOD

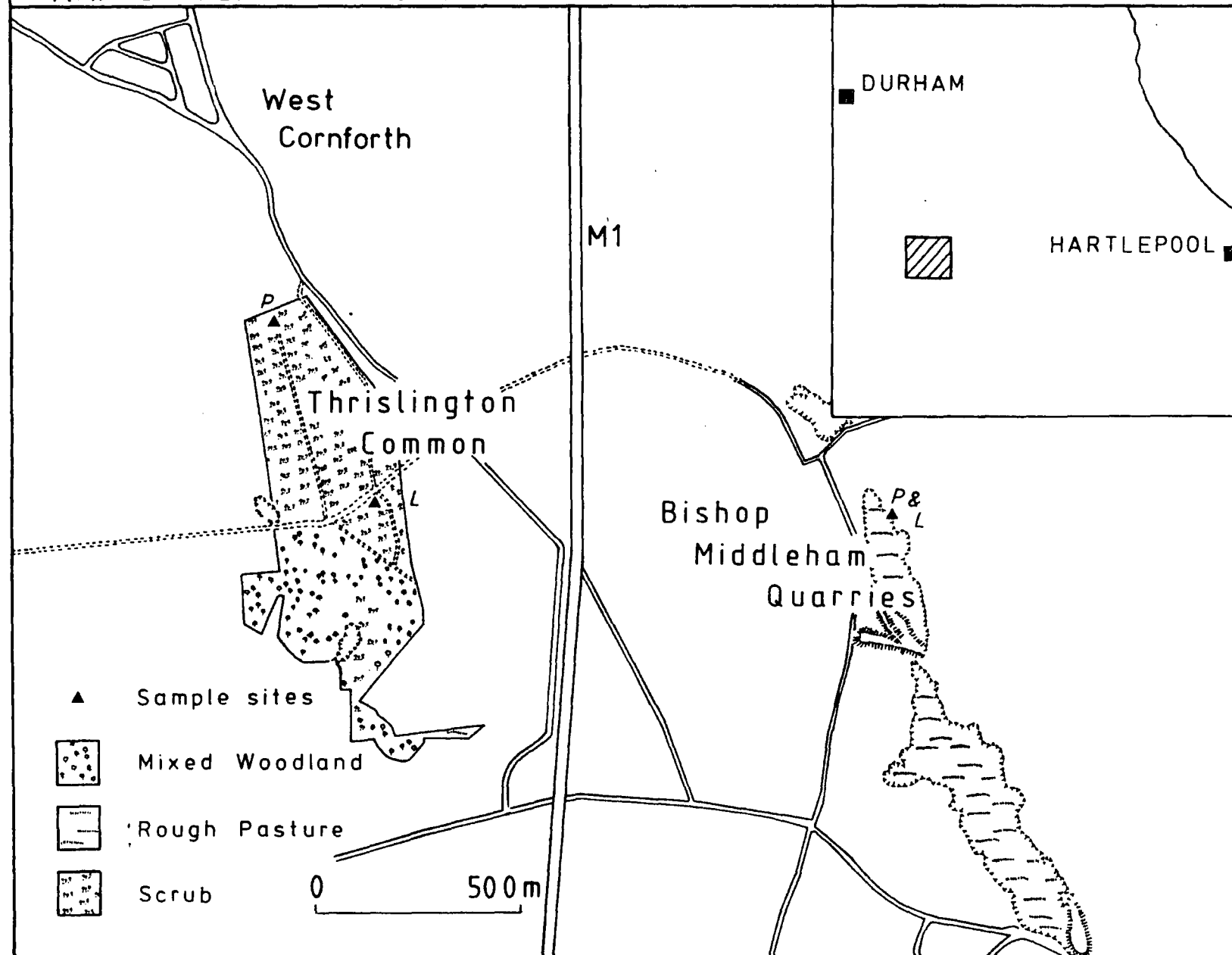
Since the object of the study was to examine differences in reproductive effort at different successional stages, two sites were selected as being representative of an early and a later successional stage. These were a quarry site and a grassland site respectively. Two species of plant were chosen which were both present at each site and which were considered most suitable for analysis. At each site 40 Plantago lanceolata plants and 40 Leontodon hispidus plants were randomly selected and permanently marked. Another 40 Plantago plants and 40 Plantago seedlings were collected from each site and transplanted into pots in a greenhouse.

All the marked plants in the field and greenhouse plants were measured at two week intervals for a period of ten weeks. For each plant measurements were recorded of plant diameter, number of leaves, flowering scape length and flowering spike length (Flowering spike length was only recorded for Plantago lanceolata). These parameters were selected as being the most suitable predictors of plant vegetative dry weight (plant diameter and number of leaves) and plant reproductive dry weight (flowering scape length and flowering spike length). This assumption was made on consideration of a set of regression analyses relating the vegetative and reproductive dry weights of a set of individuals collected from the field to various measurements of their dimensions.

The regression formula which proved most accurate in predicting the dry weights was then applied to the measurements obtained from the marked plants in the field and greenhouse. Thus an estimate of their dry weight was obtained. The most appropriate regression formula was calculated on three occasions throughout the sampling period to account for any differences in the relationship between

dry weight and the morphological dimensions which might occur over the season. Once the measurements from plants in the field and greenhouse had been converted into dry weights using the most suitable formula a value for their reproductive effort was obtained using Hickmans (1975) formula whereby  $RE = \frac{\text{total plant weight}}{\text{weight of reproductive parts}} \times 100$

# MAP SHOWING LOCATION OF SAMPLE SITES



### 3. SITES

The two sample sites chosen were similar to those sampled by Stewart (1979) and were considered to be representative of two seral stages on the magnesian limestone of the Durham escarpment. Bishop Middleham quarry (NZ 3332) was chosen as an example of an early successional stage rather than Wingate quarry (used by Stewart 1979) since the latter was being landscaped throughout the sampling period. Bishop Middleham quarry is a Nature Conservancy Council SSS1 and still retains important plant communities which have developed over the past 40 years (Doody 1977). The particular site chosen was typical of much of the area with a large amount of bare ground and a sparse patchy vegetation dominated by Lotus corniculatus associated with Festuca rubra, Plantago lanceolata, and Agrostis stolonifera (see Table 1). In such an environment there are likely to be extremes of temperature, moisture and nutrient availability. In a limestone quarry in New York Raynal (1979) quotes surface temperatures of 48°C during the growing season.

Thrislington Plantation is less than 1 km West of Bishop Middleham quarry (see Map). It is listed as Grade 1 SSS1 (A Nature Conservation Review 1977) and is considered to be the best example of ungrazed magnesian limestone grassland. The vegetation has been identified as a Seslerio-Helictotrichetum association by Shimwell (1968) and supports a number of rare species such as Linum anglicum, Antennaria dioica and Epipactis atrorubens (also found at Bishop Middleham). The area is scheduled for quarrying within the next 50 years (Doody 1977) and attempts are presently being made to determine the feasibility of transplantation as a means of maintaining the genetic stock of individual species and perhaps communities.

TABLE 1. SPECIES LISTS

|                                   | QUARRY | LEONTODON<br>GRASSLAND SITE | PLANTAGO<br>GRASSLAND SITE |
|-----------------------------------|--------|-----------------------------|----------------------------|
| <i>Achillea millefolium</i>       | 11     | 4                           | 2                          |
| <i>Agrimonia eupatoria</i>        |        |                             | P                          |
| <i>Anthyllis vulneria</i>         |        | 9                           |                            |
| <i>Astragalus danicus</i>         |        | 11                          |                            |
| <i>Bellis perennis</i>            |        |                             | 31                         |
| <i>Campanula rotundifolia</i>     |        | 6                           |                            |
| <i>Centaurea nigra</i>            | 32     | 26                          | 2                          |
| <i>Centaurea scabiosa</i>         |        | 21                          |                            |
| <i>Centaureum erythraea</i>       | 3      |                             |                            |
| <i>Cerastium fontanum</i>         |        |                             | 2                          |
| <i>Chamaenerion angustifolium</i> |        |                             |                            |
| <i>Chrysanthemum leucanthemum</i> | 35     |                             |                            |
| <i>Cirsium arvense</i>            | 3      |                             |                            |
| <i>Cirsium vulgare</i>            |        |                             | P                          |
| <i>Conopodium majus</i>           |        | 6                           |                            |
| <i>Crataegus monogyna</i>         | 1      | 7                           | 5                          |
| <i>Orepis capillaris</i>          |        |                             |                            |
| <i>Dactylorhiza fuchsii</i>       | P      | 7                           |                            |
| <i>Epipactis atrorubens</i>       |        | 2                           |                            |
| <i>Euphrasia officinalis</i>      | 20     | 22                          | 13                         |
| <i>Fragaria vesca</i>             | 11     | 11                          |                            |
| <i>Galium verum</i>               |        | 6                           |                            |
| <i>Gentianella amarella</i>       | 7      | 6                           | 1                          |
| <i>Gymnadenia conopsea</i>        | P      | 9                           | P                          |
| <i>Helianthemum chamaecistus</i>  | 2      | 21                          |                            |
| <i>Hieracium pilosella</i>        | 4      | 4                           |                            |
| <i>Hypericum perforatum</i>       | 7      | 7                           |                            |
| <i>Hypochoeris radicata</i>       |        |                             |                            |
| <i>Hypochoeris autumnalis</i>     |        |                             | 11                         |
| <i>Lathyrus pratensis</i>         |        |                             | 3                          |
| <i>Leontodon hispidus</i>         | 28     | 28                          |                            |
| <i>Linum catharticum</i>          | 31     | 22                          | 28                         |
| <i>Linum anglicum</i>             |        | 5                           |                            |
| <i>Listera ovata</i>              |        | 7                           |                            |
| <i>Lotus coniculatis</i>          | 90     | 13                          | 21                         |

TABLE I (Cont.)

|                             | QUARRY | LEONTODON<br>GRASSLAND SITE | PLANTAGO<br>GRASSLAND SITE |
|-----------------------------|--------|-----------------------------|----------------------------|
| <i>Medicago lupulina</i>    | 9      | 7                           | 11                         |
| <i>Ononis repens</i>        | 3      |                             |                            |
| <i>Plantago lanceolata</i>  | 50     | 9                           | 60                         |
| <i>Plantago major</i>       |        |                             | 4                          |
| <i>Plantago media</i>       |        | 16                          | 13                         |
| <i>Polygala vulgaris</i>    | 1      | 9                           |                            |
| <i>Potentilla reptans</i>   |        |                             | 15                         |
| <i>Potenum sanguisorba</i>  | 2      | 10                          |                            |
| <i>Primula veris</i>        | 1      | 4                           | 3                          |
| <i>Prunella vulgans</i>     | 29     | 8                           | 13                         |
| <i>Ranunculus bulbosus</i>  |        | 5                           |                            |
| <i>Rhinanthus minor</i>     |        | 11                          | 3                          |
| <i>Ranunculus acris</i>     |        |                             | 16                         |
| <i>Trifolium repens</i>     | 1      |                             | 49                         |
| <i>Rosa Canina</i>          | P      |                             |                            |
| <i>Ranunculus repens</i>    |        |                             | 6                          |
| <i>Rubus fruticosus</i>     | 2      | 3                           |                            |
| <i>Scabiosa columbaria</i>  | 10     |                             |                            |
| <i>Senecio jacobaea</i>     | P      | 1                           | P                          |
| <i>Senecio vulgaris</i>     |        |                             | P                          |
| <i>Silene dioica</i>        |        | P                           |                            |
| <i>Taxaxacum officinale</i> | 6      |                             | 13                         |
| <i>Thymus drucei</i>        | 13     | 5                           |                            |
| <i>Tragopogon pratensis</i> |        | 3                           |                            |
| <i>Trifolium pratense</i>   | 15     | 10                          | 3                          |
| <i>Tussilago farfara</i>    |        |                             |                            |
| <i>Veronica chamaedrys</i>  |        |                             | P                          |
| <i>Viola riviniana</i>      |        | P                           |                            |
| <i>Vicia cracca</i>         |        |                             | 5                          |

TABLE I(Cont.) GRASSES, SEDGES AND RUSHES

|                                | QUARRY | LEONTODON<br>GRASSLAND SITE | PLANTAGO<br>GRASSLAND SITE |
|--------------------------------|--------|-----------------------------|----------------------------|
| <i>Agropyron repens</i>        |        |                             | 2                          |
| <i>Agrostis stolonifera</i>    | 59     | 7                           | 72                         |
| <i>Agrostis tenuis</i>         | 1      | 10                          |                            |
| <i>Anthoxanthum odoratum</i>   |        | 13                          |                            |
| <i>Arrhenatherum</i>           | P      | 6                           |                            |
| <i>Brachypodium sylvaticum</i> |        |                             | 1                          |
| <i>Briza media</i>             |        | 17                          | 6                          |
| <i>Bromus crechis</i>          | 2      |                             |                            |
| <i>Cynosurus cristatus</i>     |        | 13                          | 13                         |
| <i>Dactylis glomerata</i>      | 11     | 8                           | 22                         |
| <i>Deschampsia caespitosa</i>  |        |                             |                            |
| <i>Festuca ovina</i>           | 14     |                             |                            |
| <i>Festuca rubra</i>           | 58     | 34                          | 25                         |
| <i>Helictotrichon pratense</i> |        | 2                           |                            |
| <i>Holcus lanatus</i>          | 6      | 6                           | 1                          |
| <i>Koeleria cristata</i>       | 4      | 3                           |                            |
| <i>Lolium perenne</i>          |        | 5                           | 6                          |
| <i>Phleum pratense</i>         |        |                             | 7                          |
| <i>Poa pratensis</i>           |        | 8                           | 23                         |
| <i>Sesleria albicans</i>       | 2      | 41                          |                            |
| <i>Carex flacca</i>            | 12     | 19                          | 28                         |
| <i>Luzula campestris</i>       |        |                             | 2                          |
| <i>Luzula multiflora</i>       |        |                             | 1                          |

P = present but not recorded in quadrat

Total number of species = 60 54 46

Unfortunately, on examination of the plant communities at Thrislington, it was impossible to find a site which included both of the chosen plant species in sufficient numbers (see later). It was therefore decided to use separate sites of similar size for each species. (see Map). The Leontodon site was on a gentle 6° slope facing N.W and the vegetation was composed of a large number of species dominated by Sesleria albicans and Festuca rubra. The Plantago site was approximately 250m further N. in a level area of slightly inferior grassland dominated by Agrostis stolonifera and Plantago lanceolata.

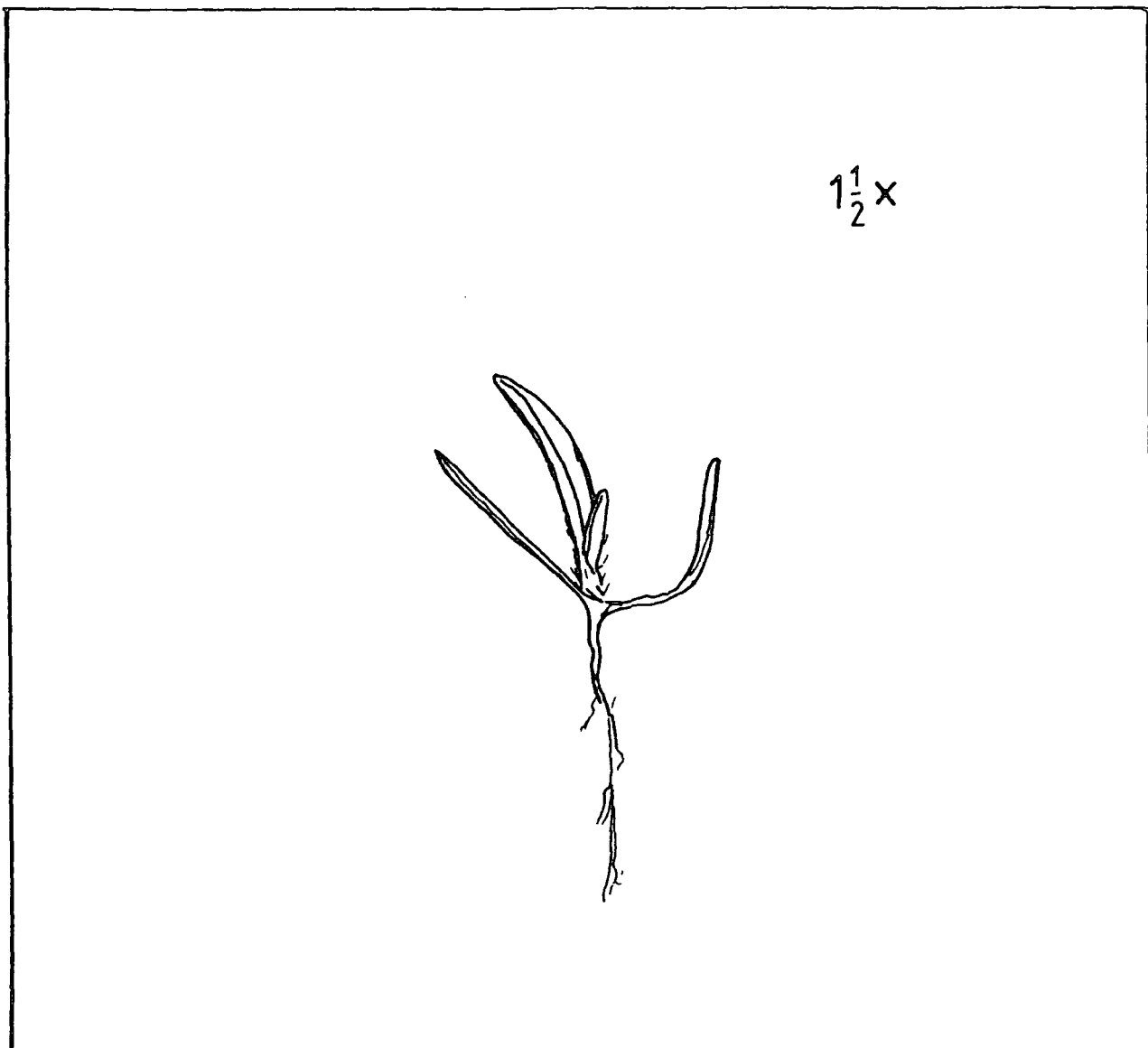


#### 4. SPECIES

The 2 species studied were selected using criteria which would enable efficient sampling and analysis. Both Plantago lanceolata and Leontodon hispidus are herbaceous perennials and are found at both sites. Stewart (1979) found that in both species individual plants are relatively easily distinguished from each other and in both plants the vegetative structures of the plant (ie leaves, stem etc) could be easily discerned from the reproductive structures (ie scape, inflorescence, seeds etc). In Leontodon the leaves are arranged in a rosette whilst in Plantago the leaves are radical and spirally arranged (Clapham, Tutin and Warburg 1959). These similar features facilitated the choice of parameters for use in the regression analyses.

Characteristically Leontodon hispidus has hispid leaves with forked hairs and this feature was useful in identification of the plant, particularly in the quarry site where there were many similar composites. Moreover P. lanceolata has a very distinctive seed and seedling (see fig 1) which enables it to be distinguished from other seedlings and pertinently, other Plantago species (Muller 1978). The seeds germinate in Spring and Autumn and seedlings could therefore be collected at the commencement of the sampling period in early May.

FIG. I DRAWING AND DESCRIPTION OF PLANTAGO  
LANCEOLATA SEEDLING (AFTER MULLER 1978)



Hypocotyl 5-20mm., glabrous, herbaceous, slightly woody.  
Seed leaves 2, sessile, strongly sheathed at  $\pm$  hairy  
base, linear  $1\frac{1}{2}$ -5cm. herb., glabrous, tip rounded-  
angular. Epicotyl absent. Leaves alternate, petiole 7-  
20mm. hairy  $\pm$  strongly sheathed at base, lanceolate-  
linear with 3 parallel nerves, base curveate,  $2\frac{1}{2}$ -4cm.,  
herbaceous, with long slender sinuate hairs. Tip rounded  
-angular, entire.

Germ. autumn-spring.

## 5. METHODS

The sampling procedure can be subdivided into two sections: methods were employed to derive regressions relating the dry weight of the sample plants to some easily measurable parameter (s) of the plant; the regression obtained from this procedure was then applied to data derived from field measurements collected at regular intervals over the growing season. Thus, the assessment of reproductive effort was possible throughout the season by means of Hickmans (1975) formula ( $RE = \text{reproductive dry weight} / \text{total dry weight}$  as a percentage).

### 5.1 Regression Methods

The first sample of plants for the regression analyses was taken one week prior to the commencement of regular field sampling. This meant that the parameters which were most suitable for measurement and provided the best estimate of plant dry weight could be determined prior to the recording of plants in the field. At each site 40 P. lanceolata and 40 L. hispidus plants were collected and put into sealed polythene bags to minimise water loss and consequent reduction in plant size. The plants were washed and stored at 5°C, then measurements were carried out at the earliest opportunity. For each plant vegetative measurements were taken of rosette diameter, number of leaves, total cumulative leaf length, total cumulative leaf breadth and a leaf area index (total leaf length x total leaf breadth). Number of scapes, total cumulative length of flowering spikes were measured, these being possible indicators of reproductive dry weight. The measurement of dimensions was carried out on entire plants since this condition would be obligatory in the field. It was calculated that 40 plants was the least number likely to produce any statistically significant results when the usual flowering percentage of the population was

taken into consideration (Stewart 1979).

The plants were then divided into reproductive matter (scape, flower, fruit seeds etc) and vegetative matter (leaves stem etc), sealed in separate envelopes, labelled and dried at 90°C until a constant dry weight was obtained. The dried plant matter was weighed on a Mettler balance to 4-decimal places. Following Abrahamson and Gadgil (1973) and Gadgil and Solbrig (1972) roots were not included in the dry weight determinations. It is extremely difficult to ensure that the entire root biomass has been obtained (Dittmer 1972) and any attempt to procure the root biomass would have made sampling time impracticable.

Data on individual plant vegetative dry weights and their corresponding dimensions were coded and punched onto computer cards. Similarly data for individual reproductive matter dry weights and the corresponding dimensions were coded. Squared values of diameter were included in these preliminary investigations since Hutchings (1975) concluded that quadratic equations gave a greater predictive accuracy. Scattergrams showing the dry weights plotted against the various measurements together with the relevant regressions and their associated statistics were produced using S.P.S.S. (Nie et al 1975) on the N.U.M.A.C. computer.

The most appropriate index of vegetative plant weight was found to be a combination of plant diameter and number of leaves (see Results). Hence, field data collection of vegetative parameters was restricted to these measurements. Data on both cumulative scape length and cumulative spike length were collected as indicators of reproductive dry weight in Plantago lanceolata. Leontodon hispidus, however, had not begun to flower at the time of the first regression determination.

Any plant species will exhibit changes in the fresh to dry weight ratio during growth ie the relationship between the measured parameters and the dry weights will change. Consequently a series of regressions should always be used to reduce errors (Hutchings 1975). Ideally a regression relationship should be determined frequently enough to eliminate significant differences between successive regressions. However, the regression analyses tended to be very time consuming and it was decided that a total of three separate regression determinations, one came out at the beginning of the sample period, one in the middle and one at the end would be sufficient to account for any significant deviations which might occur.

In the second and third regressions plants were again taken from the field, measured and separated into their component parts, dried and weighed. Some greenhouse plants (see later) were included in the third regression since these plants tended to be larger than many of the field plants. In the second and third regressions measurements taken were limited to those which had proved most suitable in the first regression (see Table 2). By the time the second set of regressions were determined L. hispidus plants had begun to flower and it was found that total cumulative scape length was the most useful predictor of Leontodon reproductive dry weight. The first regression, therefore was applicable to small plants at the beginning of the season whereas the third regression could be applied to larger plants at the end of the season. This was particularly so in P. lanceolata where the third regression included many of the large greenhouse plants. (See 'Results' for further details of regression applicability).

TABLE 2. CORRELATION COEFFICIENTS FOR FIRST SET OF  
REGRESSIONS OF WEIGHTS AGAINST VARIOUS PARAMETERS

|  |                           | <u>GRASS</u>               |                                  |                                   |
|--|---------------------------|----------------------------|----------------------------------|-----------------------------------|
| Plantago<br>Vegetative<br>Dry Weight<br>with:-   | No. of LVES               | 0.819                      | 89.437                           | 0.00001                           |
|  | Diameter                  | 0.341                      | 146.6                            | 0.01562                           |
|  | Diam <sup>2</sup>         | 0.315                      | 148.1                            | 0.023                             |
|  | N x D                     | 0.908                      | 65.2                             | 0.00001                           |
|  | N x D <sup>2</sup>        | 0.768                      | 99.87                            | "                                 |
|  | Leaf area<br>index        | 0.976                      | 33.5                             | "                                 |
|  | Total leaf<br>length      | 0.942                      | 51.9                             | "                                 |
|  | Total leaf<br>width       | 0.951                      | 47.8                             | "                                 |
| Plantago<br>Reproductive<br>Dry Weight<br>with:- | No. of Scapes             | 0.900                      | 14.95                            | "                                 |
|  | Total length<br>of Scapes | 0.863                      | 17.35                            | "                                 |
|  | Total length<br>of Spikes | 0.960                      | 9.6                              | "                                 |
| Leontodon<br>Vegetative<br>Dry Weight<br>with:-  | No. of LVES               | 0.567                      | 9.666                            | 0.00007                           |
|  | Diameter                  | 0.312                      | 11.15                            | 0.0249                            |
|  | Diam <sup>2</sup>         | 0.294                      | 11.21                            | 0.032                             |
|  | N x D                     | 0.583                      | 9.52                             | 0.00004                           |
|  | N x D <sup>2</sup>        | 0.546                      | 9.82                             | 0.00013                           |
|  | Leaf area<br>index        | 0.795                      | 7.106                            | 0.00001                           |
|  | Total leaf<br>length      | 0.719                      | 8.15                             | "                                 |
|  | Total leaf<br>width       | 0.805                      | 6.961                            | "                                 |
|  |                           | correlation<br>coefficient | standard<br>error of<br>estimate | probability<br>of<br>significance |

TABLE 2. CORRELATION OF COEFFICIENTS FOR FIRST SET OF  
REGRESSIONS OF WEIGHTS AGAINST VARIOUS PARAMETERS

|  |                           | <u>QUARRY</u>              |                                  |                                   |
|--|---------------------------|----------------------------|----------------------------------|-----------------------------------|
| Plantago<br>Vegetative<br>Dry Weight<br>with:-   | No. of LVES               | 0.307                      | 50.9                             | 0.0269                            |
|  | Diameter                  | 0.689                      | 38.7                             | 0.00001                           |
|  | Diam <sup>2</sup>         | 0.693                      | 38.57                            | "                                 |
|  | N x D                     | 0.884                      | 25.01                            | "                                 |
|  | N x D <sup>2</sup>        | 0.835                      | 29.43                            | "                                 |
|  | Leaf area<br>index        | 0.965                      | 13.88                            | "                                 |
|  | Total leaf<br>length      | 0.909                      | 22.258                           | "                                 |
|  | Total leaf<br>width       | 0.904                      | 22.85                            | "                                 |
| Plantago<br>Reproductive<br>Dry Weight<br>with:- | No. of Scapes             | 0.796                      | 10.6                             | "                                 |
|  | Total length<br>of Scapes | 0.880                      | 8.37                             | "                                 |
|  | Total length<br>of Spikes | 0.903                      | 7.577                            | "                                 |
| Leontodon<br>Vegetative<br>Dry Weight<br>with:-  | No. of LVES               | 0.652                      | 46.11                            | "                                 |
|  | Diameter                  | 0.857                      | 31.316                           | "                                 |
|  | Diam <sup>2</sup>         | 0.895                      | 27.07                            | "                                 |
|  | N x D                     | 0.909                      | 25.36                            | "                                 |
|  | N x D <sup>2</sup>        | 0.930                      | 22.26                            | "                                 |
|  | Leaf area<br>index        | 0.979                      | 12.36                            | "                                 |
|  | Total leaf<br>length      | 0.943                      | 19.6                             | "                                 |
|  | Total leaf<br>width       | 0.858                      | 31.17                            | "                                 |
|  |                           | correlation<br>coefficient | standard<br>error of<br>estimate | probability<br>of<br>significance |

TABLE 2. CORRELATION COEFFICIENTS FOR FIRST SET OF  
REGRESSIONS OF WEIGHTS AGAINST VARIOUS PARAMETERS

|  |                           |                            | <u>TOTAL</u>                     |                                   |
|--|---------------------------|----------------------------|----------------------------------|-----------------------------------|
| Plantago<br>Vegetative<br>Dry Weight<br>with:-   | No. of LVES               | 0.801                      | 78.0                             | 0.00001                           |
|  | Diameter                  | 0.533                      | 110.23                           | "                                 |
|  | Diam <sup>2</sup>         | 0.506                      | 112.39                           | "                                 |
|  | N x D                     | 0.927                      | 48.76                            | "                                 |
|  | N x D <sup>2</sup>        | 0.825                      | 73.499                           | "                                 |
|  | Leaf area<br>index        | 0.980                      | 25.5                             | "                                 |
|  | Total leaf<br>length      | 0.953                      | 39.48                            | "                                 |
|  | Total leaf<br>width       | 0.957                      | 37.48                            | "                                 |
| Plantago<br>Reproductive<br>Dry Weight<br>with:- | No. of Scapes             | 0.887                      | 13.07                            | "                                 |
|  | Total length<br>of Scapes | 0.849                      | 15.004                           | "                                 |
|  | Total length<br>of Spikes | 0.952                      | 8.628                            | "                                 |
| Leontodon<br>Vegetative<br>Dry Weight<br>with:-  | No. of LVES               | 0.742                      | 34.9                             | "                                 |
|  | Diameter                  | 0.813                      | 30.3                             | "                                 |
|  | Diam <sup>2</sup>         | 0.861                      | 26.4                             | "                                 |
|  | N x D                     | 0.921                      | 20.19                            | "                                 |
|  | N x D <sup>2</sup>        | 0.932                      | 18.76                            | "                                 |
|  | Leaf area<br>index        | 0.977                      | 11.078                           | "                                 |
|  | Total leaf<br>length      | 0.955                      | 15.4                             | "                                 |
|  | Total leaf<br>width       | 0.891                      | 23.6                             | "                                 |
|  |                           | correlation<br>coefficient |                                  |                                   |
|  |                           |                            | standard<br>error of<br>estimate |                                   |
|  |                           |                            |                                  | probability<br>of<br>significance |



## 5.2 Field and Laboratory Methods

At each sample site a permanent plot 10m by 10m was identified and marked. The vegetation was recorded using randomly located 100mm<sup>2</sup> quadrats in which the occurrence of species was noted (see Table 1). The specific plants studied (40 *Plantago* and 40 *Leontodon* at each site) were identified as those individuals nearest to randomly located points in the 10m grid. The plants were labelled and numbered using a white plastic peg which also facilitated their relocation.

In order to determine whether any observed differences between the plants at the quarry and grassland sites were genetically or environmentally cued it was necessary to remove plants from environmental influences. Since the sampling time involved in this procedure was great it was decided to restrict this experiment to one species ie *Plantago lanceolata*. Two weeks before commencement of regular sampling 40 plants from each site were carefully excavated and replanted in potting compost in 6" plastic pots. Environmental effects may well be carried over from one season to the next so in order to eliminate these effects seeds or seedlings should be studied, Since seeds were not available 40 young seedlings of uniform cotyledon size were also collected from each site. The seedlings were placed in sealed plastic tubes to minimise water loss and mechanical damage and were transplanted into potting compost in 6" pots (one per pot) as soon as possible. The plants and seedlings were kept in the greenhouse in an environment which simulated external conditions as far as possible.

Measurements of plant diameter, number of leaves, cumulative scape length and cumulative spike length were then taken of all these plants (both field and greenhouse) at 2 week intervals commencing on June 1st. Other studies have used sampling intervals of 3 weeks and more on a variety of plants eg Newell and Tramer (1978) and Bostock and Benton (1979) so 2 weeks was considered an adequate time interval. Sampling was subjectively terminated when the maj-

ority of Plantago had seeded. (Altogether 5 samples were taken).

In the laboratory measurements of Plantago spike length and number of 2 - seeded capsules were noted and a regression relating the two was computed. It was hoped that this would provide an additional measure of reproductive achievement.

In order to assess the relative germinability of Plantago seeds from each site 25 seeds of each type were placed on damp filler paper in Petri dishes and allowed to germinate. In total there were 6 different types of seed:- Field quarry seed, quarry seed from plants grown for one season in greenhouse and quarry seed from seedlings grown in greenhouse; field grassland seed, grassland seed from plants grown for the season in greenhouse and grassland seed from seedlings grown in greenhouse. The experiment was repeated using Petri dishes covered in foil to exclude light. Three replicate experiments were conducted for statistical validity. The numbers of seeds which had germinated after four weeks were noted.

The number of vegetative rosettes produced by each plant grown for one season in the greenhouse at the end of the sampling period was also recorded.

The data from the field and greenhouse sampling were converted to dry weight using the appropriate regression formula. The results were then analysed using various procedures available with S.P.S.S.

## 6. RESULTS

### 6.1 Regressions

Scattergrams of the various measured parameters against the dry weights using the first set of regression data were produced and examined. The validity of each parameter as a predictor of plant dry weight was then assessed by means of their correlation coefficients. The data were found to be slightly positively skewed and theoretically a transformation should be applied to such data before any correlation or regression analysis. However, one of the principle objects of the study was to predict absolute values of plant dry weight (particularly in considering the mechanisms involved in the decision to flower) and any transformation of the data at this stage would have made this impossible. It should be noted, however, that the slight skewness may make some difference in the absolute values of the correlation coefficients. Nevertheless their relative relationships will not change.

The correlation coefficient is an index which reflects the degree to which changes in direction and magnitude in one set of data (ie the dry weight values) are associated with comparable changes in the other set (ie the measure parameter). Whittaker and Woodwell (1968) have suggested an alternative method for expression of the relative accuracy of predictions made from regressions. The Standard Error of the Estimate for a Regression.

$$S E = \sqrt{(\sum d^2 / n - 1)}$$

In order to express the relative spread of points from a linear regression the Standard Error was divided by the mean value of the y - observations to produce an estimate of relative error. However, this value is also influenced by skewness and under these circumstances the correlation coefficient was considered to be an adequate index

of the relative accuracy of the predictions.

The correlation coefficients for the various parameters analysed in the first regression sample are shown in Table 2. From this table it is apparent that the best predictors of vegetative dry weight for both Leontodon and Plantago was the leaf area index ( $R = 0.98$  for both plants) (see figs 2 and 1 a and b). Unfortunately this parameter was far too time consuming to collect in the field as were total leaf length and total leaf breadth. Consequently either no. of leaves x diameter ( $R = 0.93$  for Plantago) or no. of leaves x diameter squared ( $R = 0.93$  for Leontodon) (see figs 2iii and iv) were chosen as being most suitable. A composite regression including both the plants from the quarry site and plants from the grassland site was selected because it produced a higher correlation coefficient than either site treated separately.

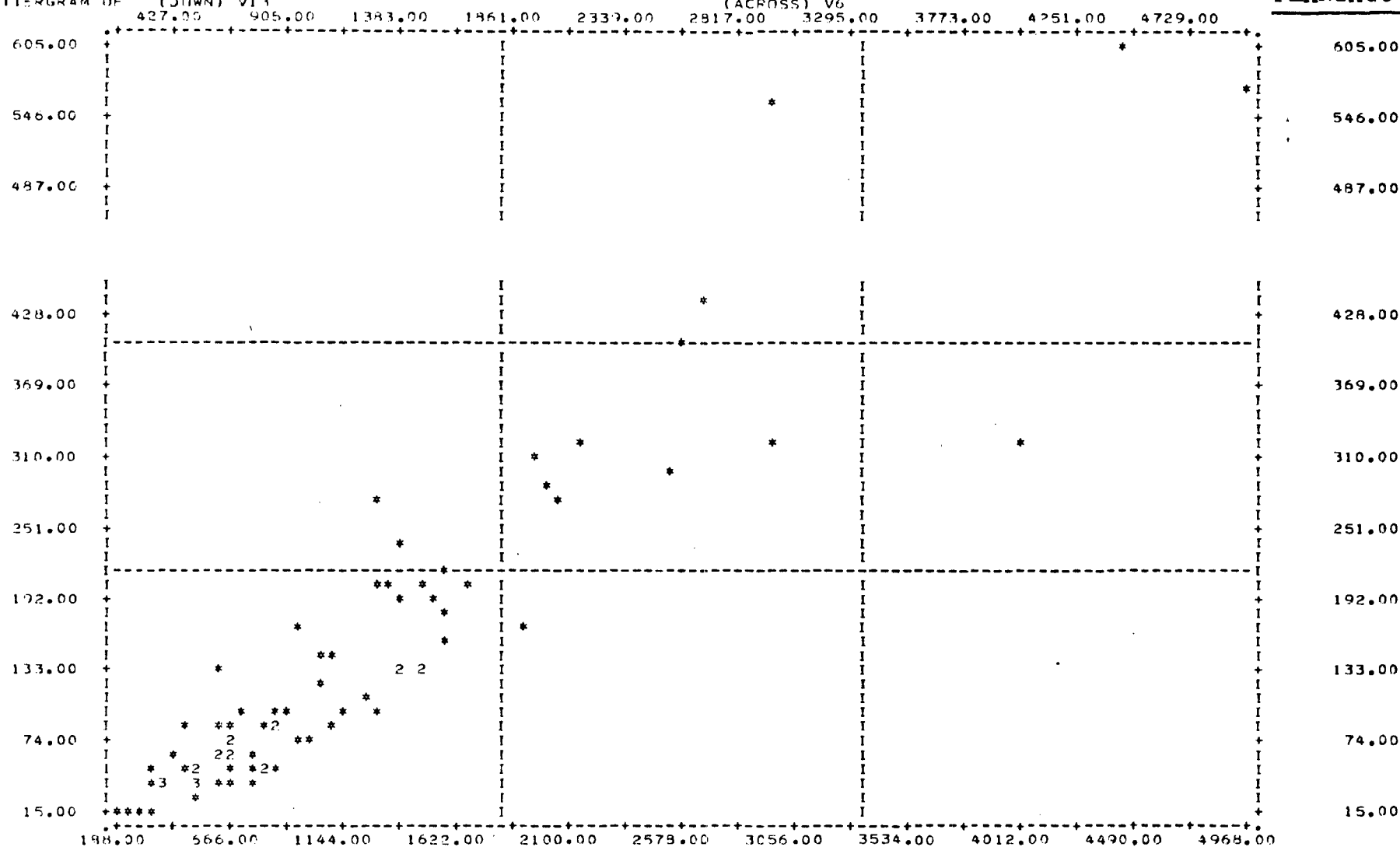
It is also evident from Table 2 that there are some interesting differences in morphology between the two species and furthermore, between similar species at different sites. Leontodon has a much better correlation between vegetative dry weight and diameter (0.81) than Plantago (0.53) suggesting that Leontodon has a more compact form. There is also a striking difference between the Leontodon plants at the quarry site, having a good correlation with diameter (0.85) and the grassland plants having a poor correlation with diameter (0.31). Similarly Plantago plants at the quarry site have a higher correlation with diameter (0.68) than those at the grassland site (0.34).

In the first regression analysis the best indicator of Plantago reproductive weight was the total length of the flowering spike. In subsequent regressions, however the total length of the scape was a more accurate predictor. This was to be expected since as the scape enlarged over the season the relative importance of the

FILE NONAME (CREATION DATE = 09/06/79)  
SCATTERGRAM OF (DOWN) V13

(ACROSS) V6

PLANTAGO LANCEOLATA



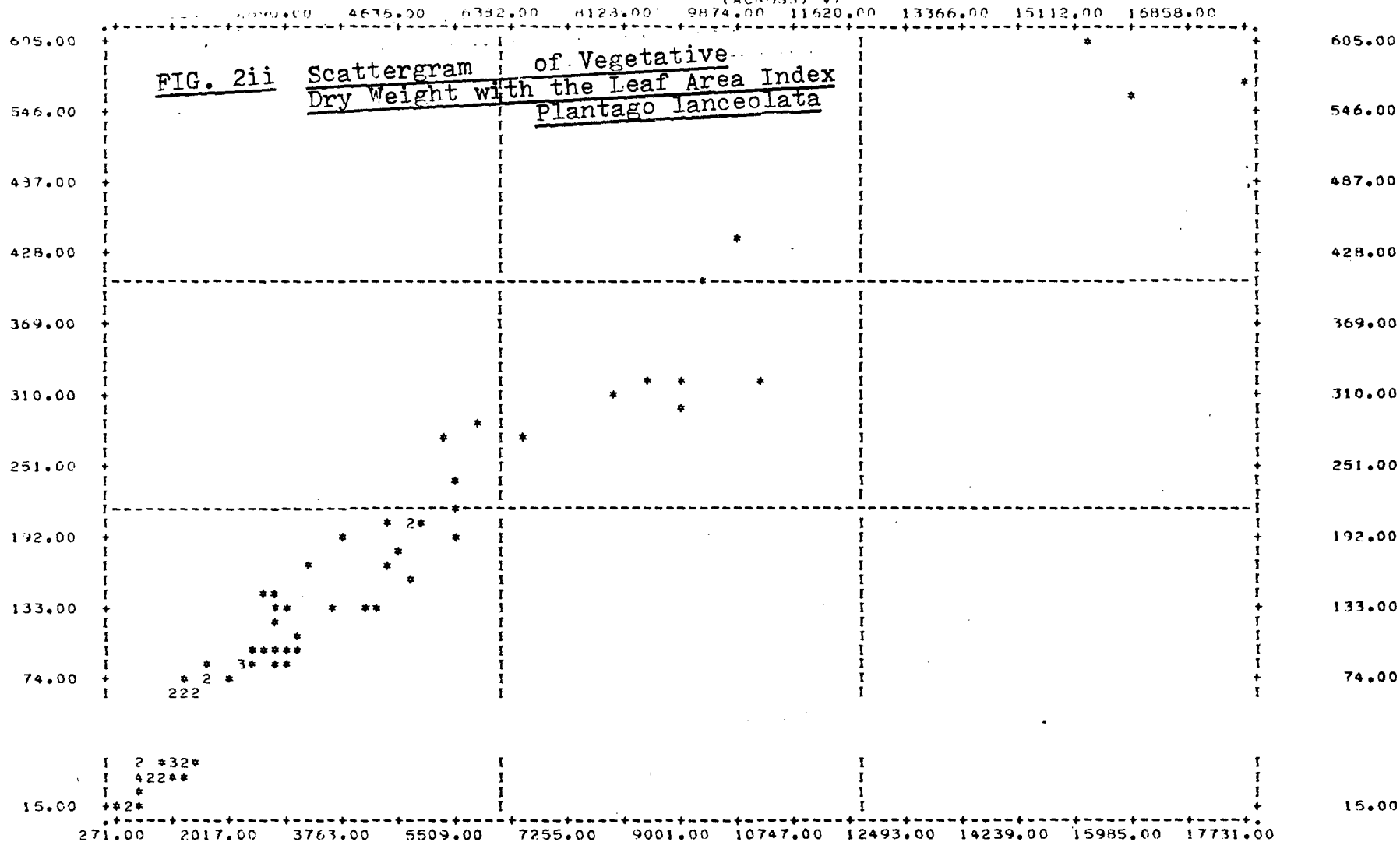
FIRST REGRES SCATTERGRAMS

09/06/79

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## STATISTICS..

|   |          |                  |   |                  |              |   |         |
|---|----------|------------------|---|------------------|--------------|---|---------|
| CORRELATION (R)-                                    | 0.92739  | R SQUARED        | - | 0.86005          | SIGNIFICANCE | - | 0.00001 |
| STD ERR OF EST -                                    | 48.76053 | INTERCEPT (A) -  | - | -14.93216        | SLOPE (B)    | - | 0.13123 |
| THE REGRESSION LINE CUTS THE MARGINS OF THE PLOT AT |          |                  |   |                  |              |   |         |
| A VALUE OF 9.73829 ON THE LEFT MARGIN               |          |                  |   |                  |              |   |         |
| A VALUE OF 4814.03203 ON THE TOP MARGIN             |          |                  |   |                  |              |   |         |
| PLOTTED VALUES -                                    | HC       | EXCLUDED VALUES- | 0 | MISSING VALUES - | 0            |   |         |



FIRST REGRES SCATTERGRAMS

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## STATISTICS..

|   |          |                  |   |                  |              |   |         |
|---|----------|------------------|---|------------------|--------------|---|---------|
| CORRELATION (R)-                                    | 0.98062  | R SQUARED        | - | 0.96162          | SIGNIFICANCE | - | 0.00001 |
| STD ERR OF EST -                                    | 25.53523 | INTERCEPT (A) -  | - | 14.76862         | SLOPE (B)    | - | 0.03586 |
| THE REGRESSION LINE CUTS THE MARGINS OF THE PLOT AT |          |                  |   |                  |              |   |         |
| A VALUE OF 24.48569 ON THE LEFT MARGIN              |          |                  |   |                  |              |   |         |
| A VALUE OF 16790.09375 ON THE TOP MARGIN            |          |                  |   |                  |              |   |         |
| PLOTTED VALUES -                                    | 80       | EXCLUDED VALUES- | 0 | MISSING VALUES - | 0            |   |         |

\*\*\*\*\* IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.

# Fig. 2iii Scattergram of Vegetative Dry Weight with

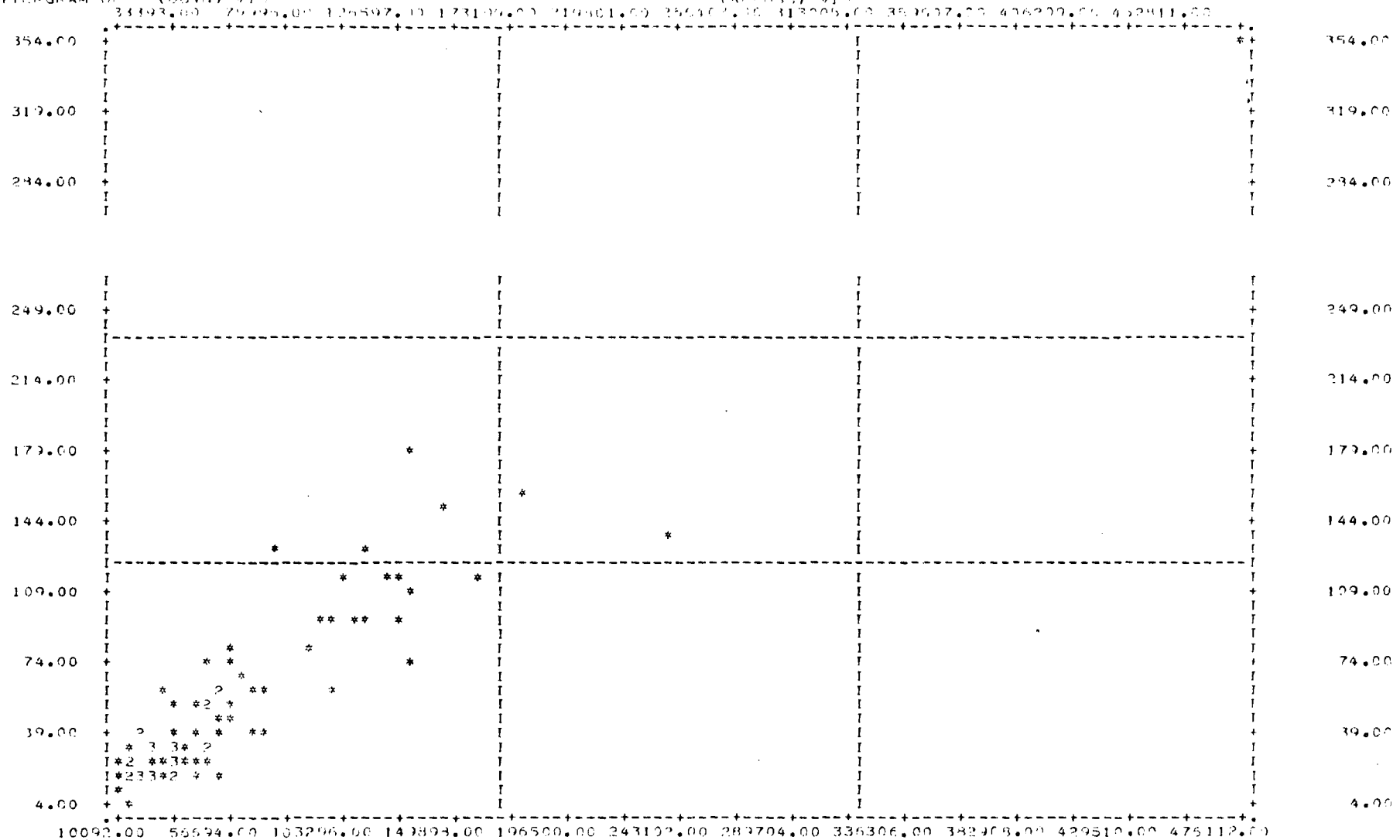
No. of Leaves x Diameter<sup>2</sup>

Leontodon hispidus

FIRST REGRES SCATTERGRAMS

FILE NONAME (CREATION DATE = 09/14/79)  
SCATTERGRAM OF (DOWN) V13

(ACROSS) V15



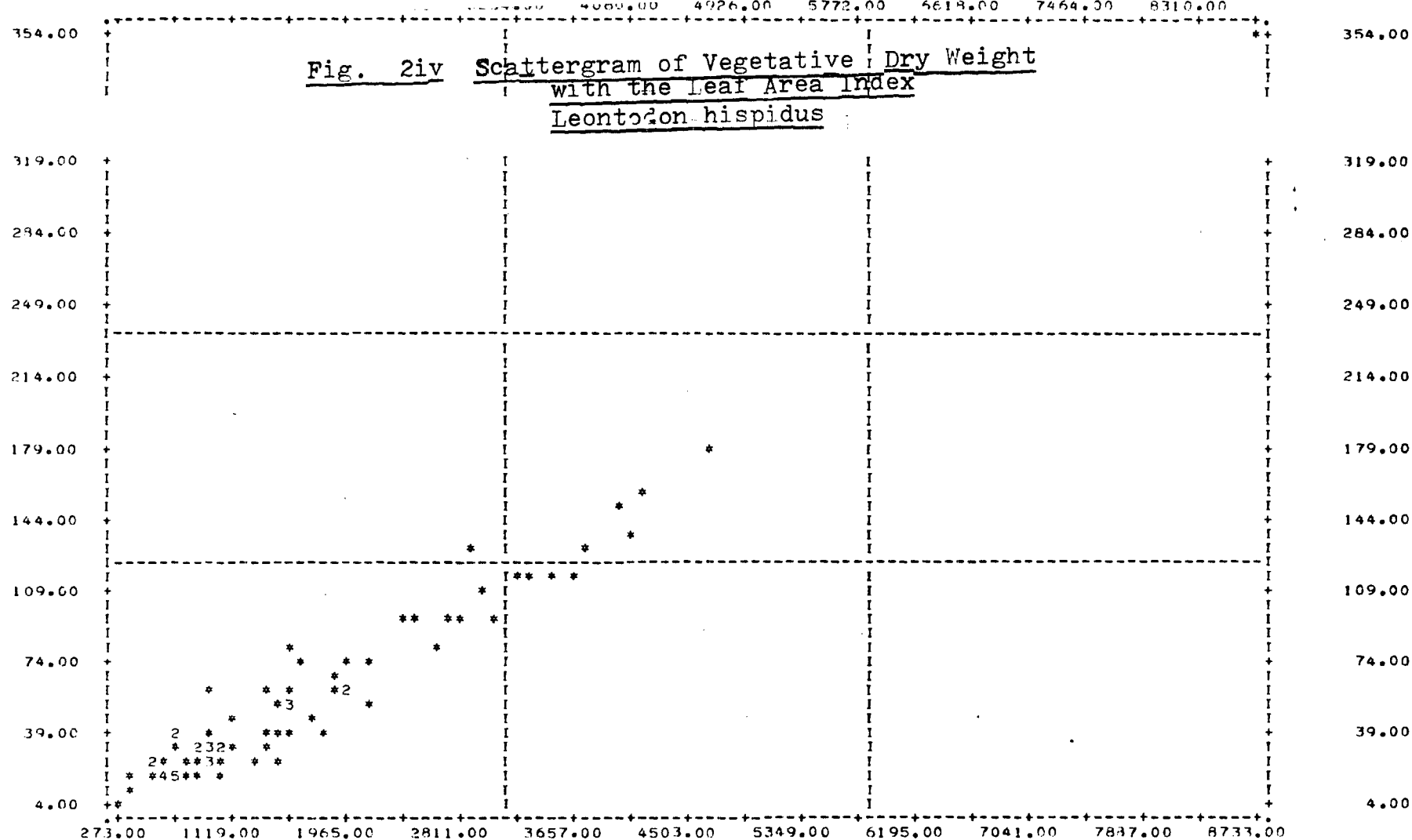
FIRST REGRES SCATTERGRAMS

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## STATISTICS..

|   |          |                  |   |                  |              |   |         |
|---|----------|------------------|---|------------------|--------------|---|---------|
| CORRELATION (R)-                                    | 0.93992  | R SQUARED        | - | 0.87333          | SIGNIFICANCE | - | 0.00001 |
| STD ERR OF EST -                                    | 18.76306 | INTERCEPT (A) -  |   | 10.71903         | SLOPE (B)    | - | 0.00275 |
| THE REGRESSION LINE CUTS THE MARGINS OF THE PLOT AT |          |                  |   |                  |              |   |         |
| A VALUE OF 18.25358 ON THE LEFT MARGIN              |          |                  |   |                  |              |   |         |
| A VALUE OF 464554.43750 ON THE TOP MARGIN           |          |                  |   |                  |              |   |         |
| PLOTTED VALUES -                                    | 30       | EXCLUDED VALUES- | 0 | MISSING VALUES - | 0            |   |         |



FIRST REGRES SCATTERGRAMS

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STATISTICS..

CORRELATION (R) - 0.97714 R SQUARED - 0.95480 SIGNIFICANCE - 0.00001

STD ERR OF EST - 11.07812 INTERCEPT (A) - -6.56834 SLOPE (B) - 0.03838

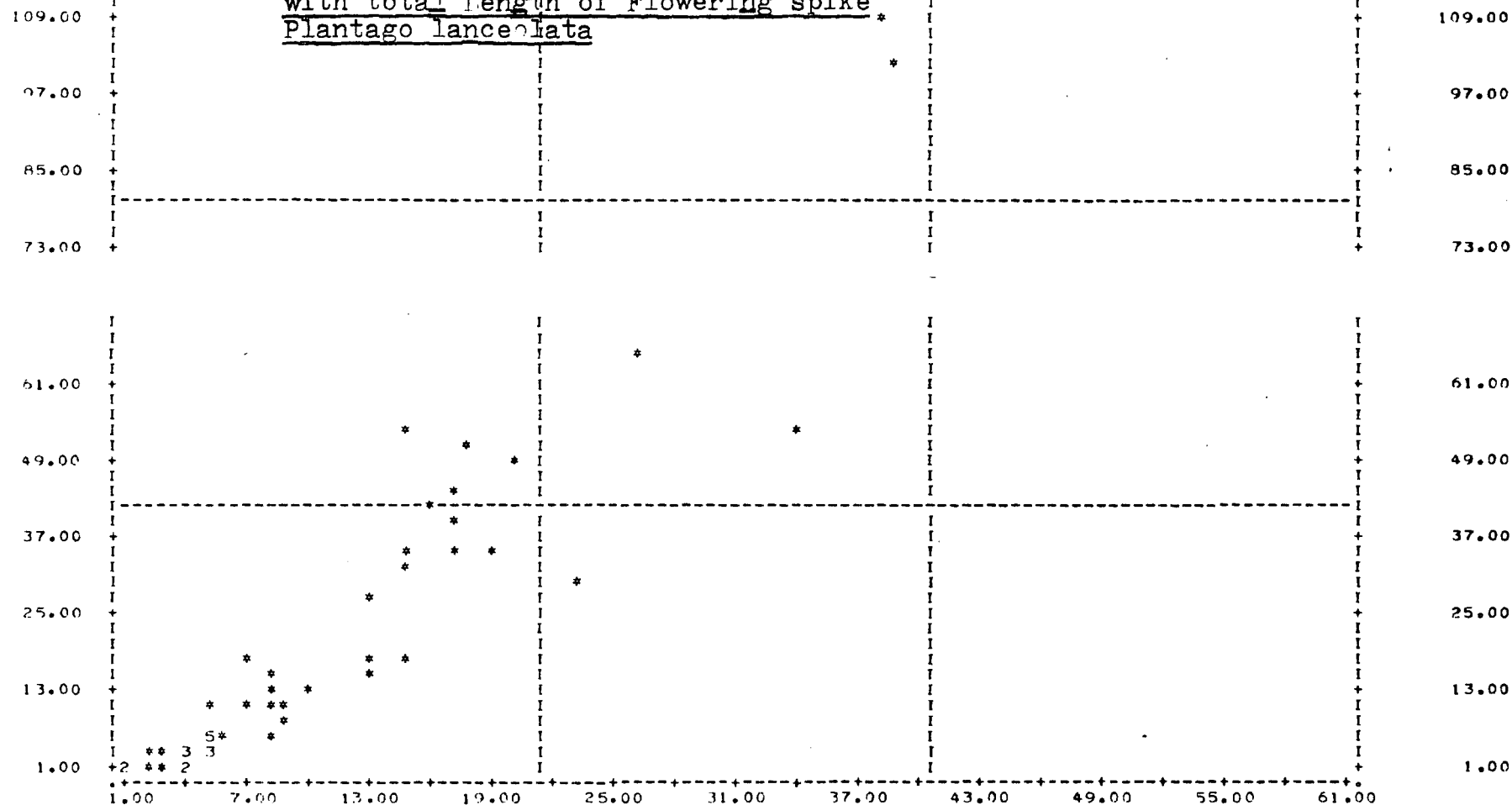
THE REGRESSION LINE CUTS THE MARGINS OF THE PLOT AT  
A VALUE OF 3.90982 ON THE LEFT MARGIN  
A VALUE OF 328.61768 ON THE RIGHT MARGIN

PLOTTED VALUES - 40 EXCLUDED VALUES - 0 MISSING VALUES - 0

\*\*\*\*\* IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.



Fig. 2v Scattergram of Reproductive Dry Weight  
with total Length of Flowering spike  
Plantago lanceolata



FIRST REGRES SCATTERGRAMS

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STATISTICS..

|   |         |                  |   |                  |              |   |         |
|---|---------|------------------|---|------------------|--------------|---|---------|
| CORRELATION (R)-                                    | 0.95277 | R SQUARED        | - | 0.90777          | SIGNIFICANCE | - | 0.00001 |
| STD ERR OF EST -                                    | 8.62817 | INTERCEPT (A) -  | - | -5.92718         | SLOPE (B)    | - | 2.44766 |
| THE REGRESSION LINE CUTS THE MARGINS OF THE PLOT AT |         |                  |   |                  |              |   |         |
| A VALUE OF 1.84059 ON THE BOTTOM MARGIN             |         |                  |   |                  |              |   |         |
| A VALUE OF 52.83702 ON THE TOP MARGIN               |         |                  |   |                  |              |   |         |
| PLOTTED VALUES -                                    | 50      | EXCLUDED VALUES- | 0 | MISSING VALUES - | 30           |   |         |

\*\*\*\*\* IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.

FIRST REGRES SCATTERGRAMS

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terminal flowering spike in the total reproductive weight became less. Total scape length was considered to be the only reliable measure of reproductive dry weight in Leontodon since the flower and fruit altered dimensions throughout the season.

This procedure for selecting regressions was carried out on the 2nd and 3rd samples. The exact parameters which were selected and their associated regression values are given in Table 3. The scattergrams for these regressions are included in the Appendix. The fact that different regressions are necessary over the season indicates that the relationship between the dry weight of the plant and its dimensions does change over the season. All the regression equations were then applied to the field and greenhouse sample data in order to convert these measurements to dry weights. In the case of Plantago the problem of when to apply each regression was resolved subjectively. Since the first regression sample was taken just before commencement of field sampling and growth of the plants at this time was rapid, this regression was only applied to the first field and greenhouse sample. The third Plantago regression included some very large greenhouse plants and when this regression equation was applied to the field data a large number of negative values were obtained (see discussion). The third regression was therefore not applied to field data, only data concerning greenhouse plants.

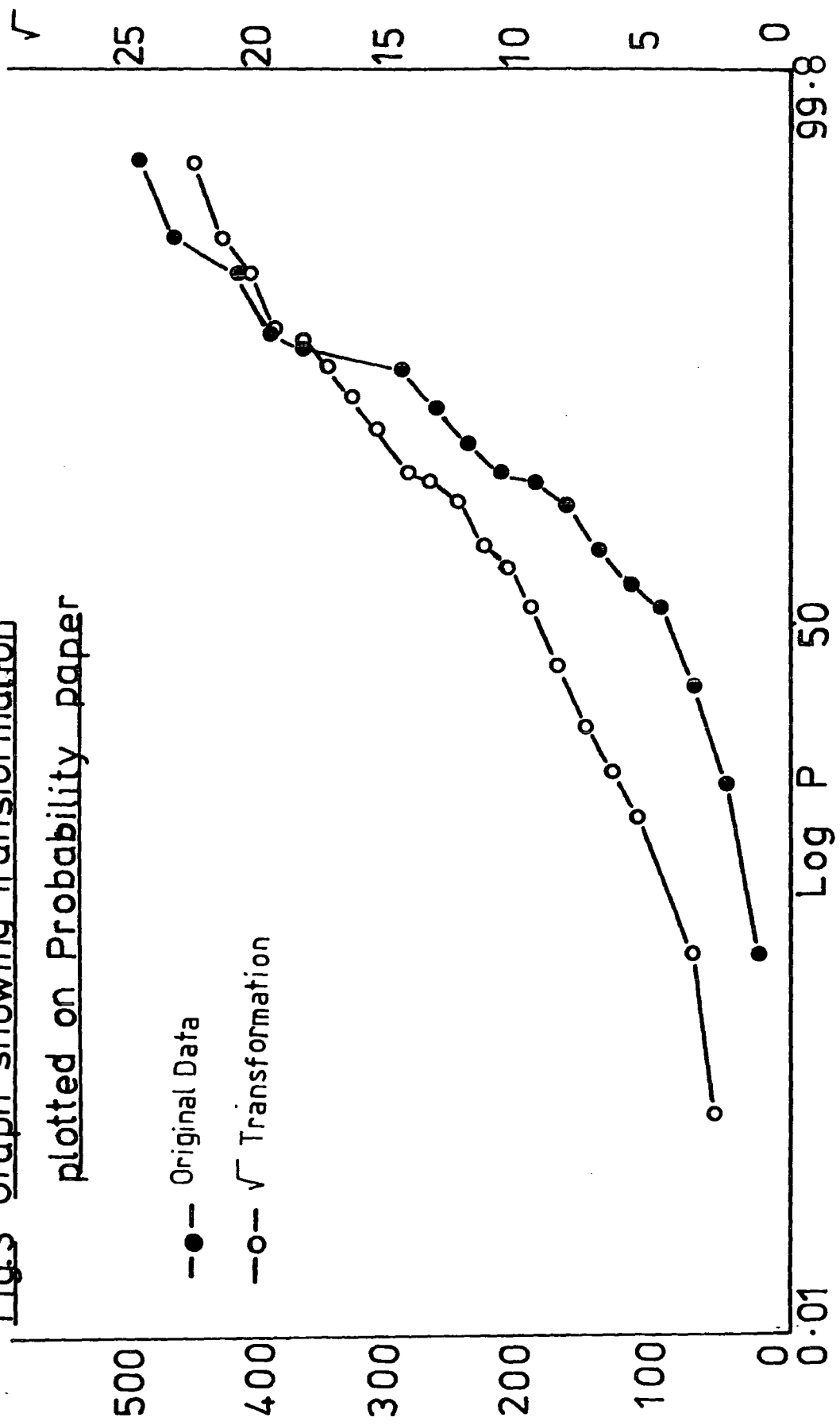
On examination of the dry weight data for Leontodon it was evident that the 1st and 3rd regression equations produced many spurious negative values (see discussion for possible explanations) and it was decided to restrict analysis to the 2nd equation values.

Since some data were again found to be slightly positively skewed a square root transformation was applied before calculation

TABLE 3. REGRESSION EQUATION FIGURES.

| <u>REGRESSION</u>   | <u>a</u>   | <u>b</u> | <u>x</u>                            |
|---|------------|----------|-------------------------------------|
| 1st. <u>Plantago</u> for<br>Vegetative<br>Dry Weight  | -14.93216  | 0.13123  | No. of leaves x<br>diameter         |
| 2nd. <u>Plantago</u> for<br>Vegetative<br>Dry Weight  | 95.39337   | 0.00049  | No. of leaves x<br>diameter         |
| 3rd. <u>Plantago</u> for<br>Vegetative<br>Dry Weight  | 98.76514   | 0.19403  | No. of leaves x<br>diameter         |
| 1st. <u>Leontodon</u><br>for Vegetative<br>Dry Weight   | 10.71903   | 0.00075  | No. of leaves x<br>diameter         |
| 2nd. <u>Leontodon</u><br>for Vegetative<br>Dry Weight   | -14.47674  | 0.15567  | No. of leaves x<br>diameter         |
| 3rd. <u>Leontodon</u><br>Vegetative<br>Dry Weight   | 58.75476   | 0.00037  | No. of leaves x<br>diameter         |
| 1st. <u>Plantago</u> for<br>Reproductive<br>Dry Weight  | -5.92718   | 2.44766  | Total length of<br>Flowering Spikes |
| 2nd. <u>Plantago</u> for<br>Reproductive<br>Dry Weight  | -59.82900  | 0.65728  | Total length of<br>Scapes           |
| 3rd. <u>Plantago</u> for<br>Reproductive<br>Dry Weight  | -159.44195 | 0.99643  | Total length of<br>Scapes           |
| 2nd. <u>Leontodon</u><br>for Reproductive<br>Dry Weight<br>(Plants were not<br>Flowering at time<br>of First<br>Regression) | 1.31637    | 0.76623  | Total length of<br>Scapes           |
| 3rd. <u>Leontodon</u><br>for Reproductive<br>Dry Weight   | -12.53409  | 0.68362  | Total length of<br>Scapes           |

Fig.3 Graph showing Transformation  
plotted on Probability paper



of t - tests to determine significant differences between species and sites. When values from the first set of field data were plotted on probability paper a square root transformation was the most satisfactory in approximating the straight line characteristic of normal data (see fig 3). The transformation was applied to enable the adoption of parametric methods of statistical analysis which are generally considered to be preferable to non-parametric methods (Sokal and Rolf 1969).

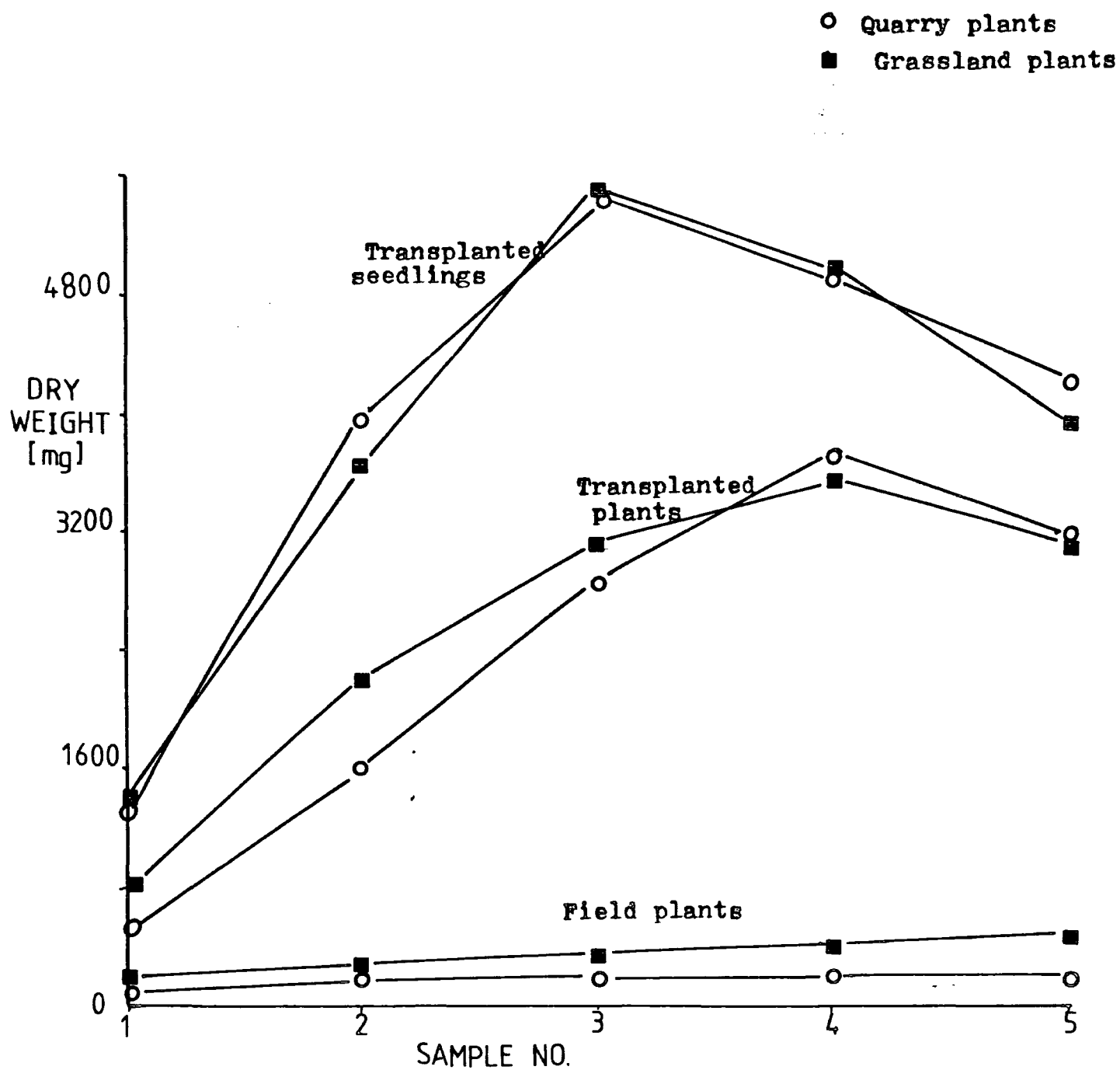
## 6.2 Plantago Lanceolata

### i. Vegetative Dry Weight

The vegetative dry weights of the 3 classes of Plantago are shown in table 4 and fig 4. There is a marked difference in the vegetative weights attained by each class of plant. The greatest weights are achieved by the seedlings which reach an average peak of 5343 mg. in the 3rd sample week, after which they begin to decline. The transplanted greenhouse plants reach an average peak of 3646 mg. in the 4th sample week. Although the seedlings and plants began the sampling period with highly significant differences in vegetative dry weight ( $P < 0.001$ ), this difference becomes less marked over the time period until it becomes insignificant in the last sample week. The Plantago plants growing in the field have much lower vegetative weights. The Quarry Plantago plants reach a peak of 199.7mg in the 4th week then begin to decline slightly. In the fifth week the grassland Plantago plants have mean vegetative weights of 450.8mg and do not show any evidence of a decline within the sample period. The Plantago plants in the field always have a significantly different mean vegetative dry weight from the transplanted plants in the greenhouse and hence also from the seedlings.

('Seedlings' is used as a distinguishing term meaning those plants

**FIG.4 DRY WEIGHT OF VEGETATIVE MATTER**  
**PLANTAGO LANCEOLATA**



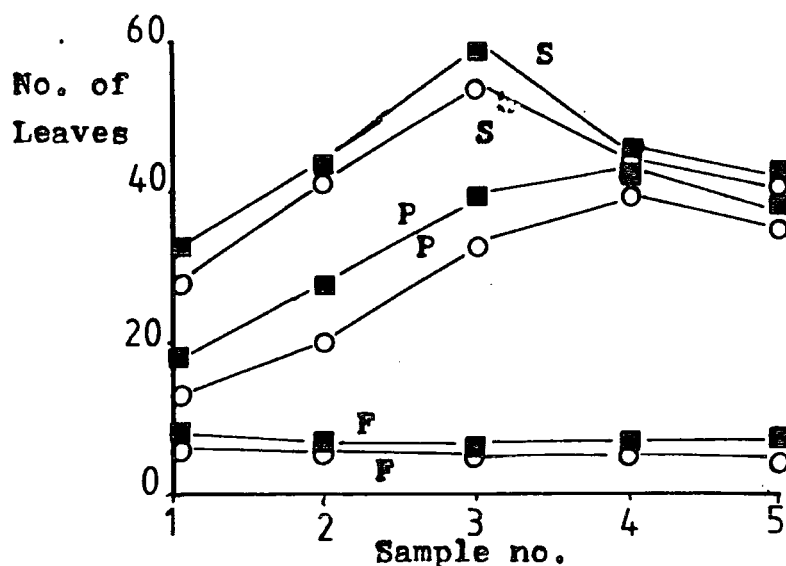
in the greenhouse which were transplanted as seedlings).

In the field Plantago plants, there is always a significant difference in vegetative dry weight between those from the grassland and those from the quarry ( $P < 0.001$ ). The grassland Plantago plants are always larger and this trend becomes more pronounced as the season progresses. In the first two sample weeks there is a difference between the grassland greenhouse plants and quarry greenhouse plants ( $P = < 0.01$ ) but this gradually disappears until in the final week the plants can virtually be regarded as coming from the same population ( $P = 0.818$ ). At no time are the seedlings from the grassland and the seedlings from the quarry significantly different.

These figures for vegetative dry weight are based on the data collected on plant diameter and number of leaves and it is interesting to examine these values separately. The seedlings again have the largest number of leaves with a maximum average/plant of 56.6 in the third week. The greenhouse plants reach a maximum average of 42 leaves/plant in the 4th week whilst the field plants have a maximum number of leaves at the beginning of sampling (7.7/plant for the grassland and 6.6/plant for quarry). Grassland plants consistently have a larger mean number of leaves in all classes but this is only statistically significant at the end of field sampling and beginning of greenhouse plant sampling (see table 5 and fig 5).

The difference in diameter between the various classes of plant is not as pronounced (see table 6 fig 6). Both seedlings and greenhouse plants reach a maximum in the 4th week with mean diameters/plant of 549mm and 442mm respectively. Field Plantago maxima are in the fourth week at the quarry (173mm) and fifth week at the grassland (276mm). The seedlings and greenhouse plants never display any significant difference in diameters at the two sites but in the field populations

**FIG. 5 NUMBER OF LEAVES**  
**PLANTAGO LANCEOLATA**



S = Transplanted seedlings

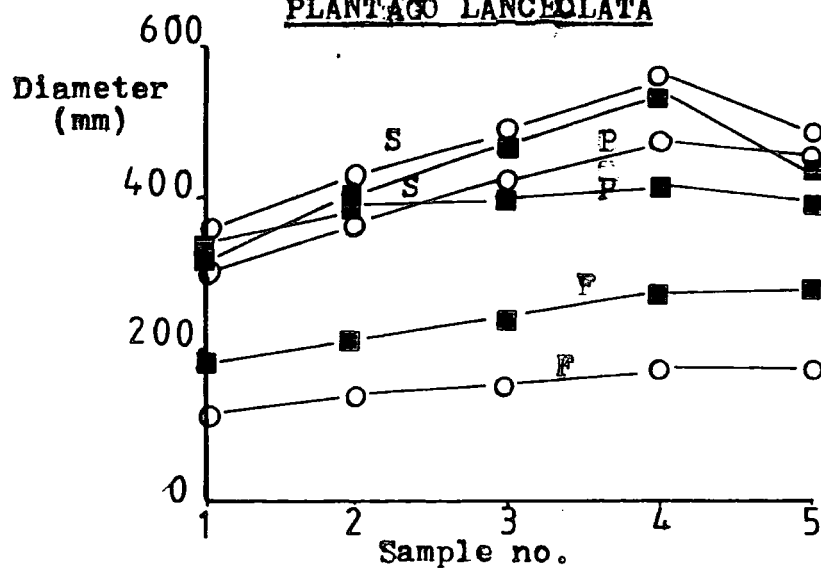
P = Transplanted plants

F = Field plants

O Quarry plants

■ Grassland plants

**FIG. 6 DIAMETER OF ROSETTES**  
**PLANTAGO LANCEOLATA**





the grassland plants are always larger ( $P < 0.001$ ). The differences in vegetative dry weight between the two populations in the field can be mainly attributed to differences in diameter. However, towards the end of the season differences in the number of leaves per plant contribute towards determining the vegetative dry weight of each plant.

#### ii Reproductive Dry Weight

The mean reproductive dry weight/plant is shown for the flowering population in fig 7a and for the total population in fig 7b. There is little difference in the general pattern between these two populations, the total population means being slightly lower in value. In all 3 classes the peak reproductive biomass is in the final week and, similarly to the vegetative dry weights, the seedlings have the highest production (5723mg), followed closely by the greenhouse plants (4482mg) then a steep decline to the field plants (300mg). It is interesting to note that in the seedlings the steep rise in reproductive biomass between the second and third week is followed by a decline in vegetative production between the third and fourth weeks. Similarly in the greenhouse plants, the steep rise in reproductive production between the third and fourth weeks is followed by a decline in vegetative production between the fourth and fifth weeks.

The difference between the field plants and greenhouse plants in reproductive dry weight is always significant, particularly towards the end of sampling but any difference between the greenhouse plants and seedlings is less distinct. At the commencement of sampling the difference between the quarry plants is significant ( $P = < 0.01$ ) whilst at the end of sampling the difference between the grassland plants is significant ( $P = < 0.001$ ). Tables 7a and 7b show that although the grassland plants consistently have a greater reproductive production in the field and seedlings this difference is only significant

**FIG. 7a** MEAN DRY WEIGHT OF REPRODUCTIVE MATTER  
FOR FLOWERING PLANTS  
PLANTAGO LANCEOLATA

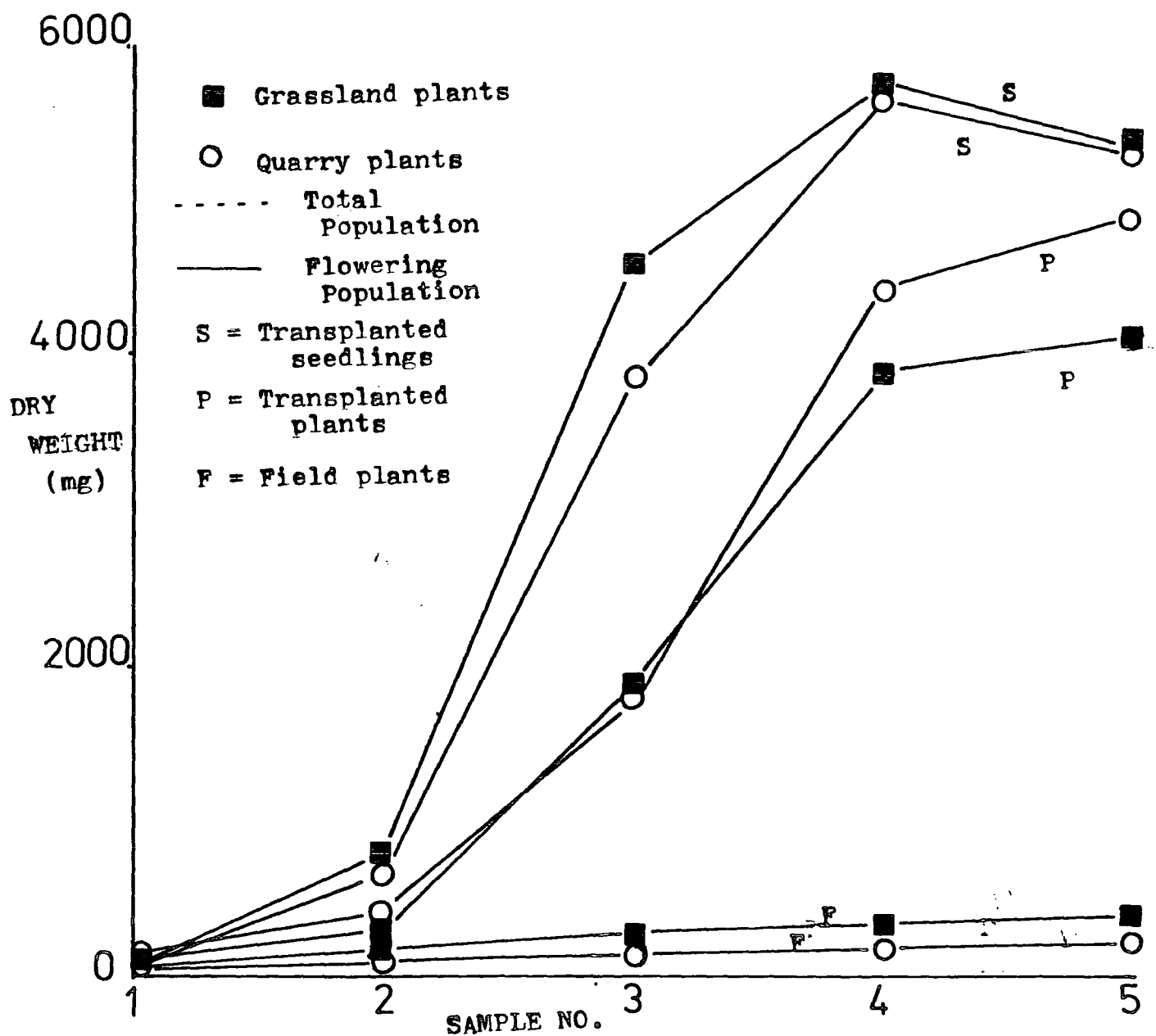
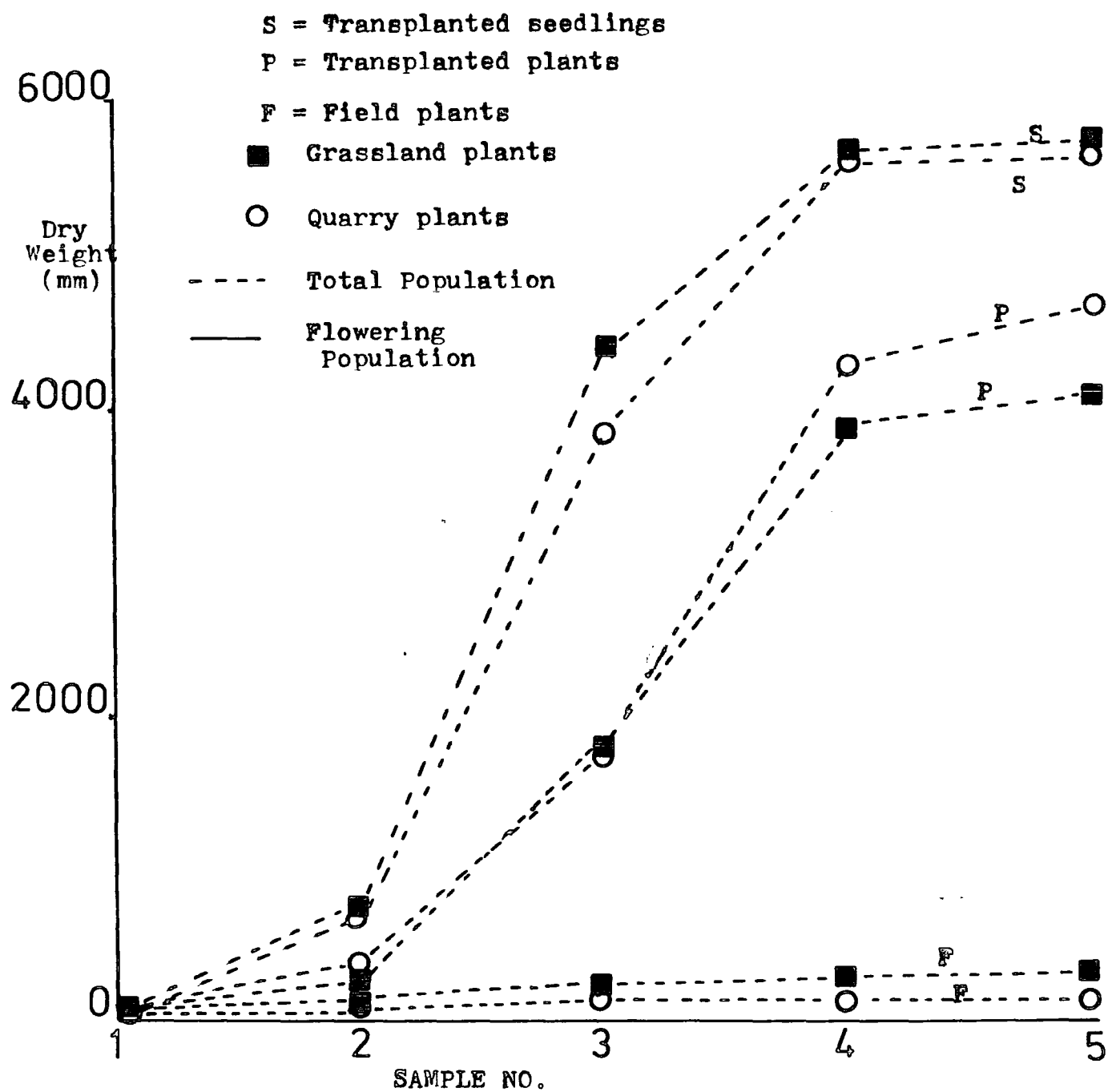


FIG. 7b MEAN DRY WEIGHT OF REPRODUCTIVE MATTER  
FOR TOTAL POPULATION  
PLANTAGO LANCEOLATA



in the field populations.. The quarry greenhouse plants often have a larger reproductive production but the probability of this difference being significant is never greater than 0.08.

### iii Reproductive Effort

The reproductive effort defined as 'the reproductive dry weight as a percentage of the total weight' for all three classes of Plantago is shown in figs 8a and 8b.. The curves taken by the greenhouse plants and seedlings are very similar, reaching a mean maximum per flowering plant in the final week at 58.9% and 58.4% respectively. However the greenhouse plants have a significantly higher mean (10.5% as compared with 3.4%) at the commencement of sampling. The field Plantago plants have a significantly higher mean R.E. at the commencement of sampling (19.25%) but begin to lead off in the third week ending with a significantly lower mean (42.5%). At no time is there any significant difference between quarry and grassland plants either in the field, greenhouse plants or seedlings. Nevertheless it appears that in the field grassland plants commence with a higher R.E. and finish with a lower R.E. whilst in the greenhouse plants grassland plants consistently have a lower R.E. and in the seedlings grassland plants consistently have a higher mean R.E. The mean population R.E. for the greenhouse plants and seedlings closely follows that of the flowering population R.E. shown in fig 8b. This is because virtually all of these plants flowered. The mean population R.E. for the plants in the field, however fluctuates considerably the maxima being at the grassland site - 27.1% in the third week - and at the quarry site - 16.2% in the fourth week.

An alternative method for determining reproductive effort might be to look at the numbers of seeds produced by a plant. It would be difficult to count total numbers of seeds in practise but a regression could be calculated relating a measurable characteristic

**FIG. 8a MEAN REPRODUCTIVE EFFORT OF FLOWERING PLANTS**

**PLANTAGO LANCEOIATA**

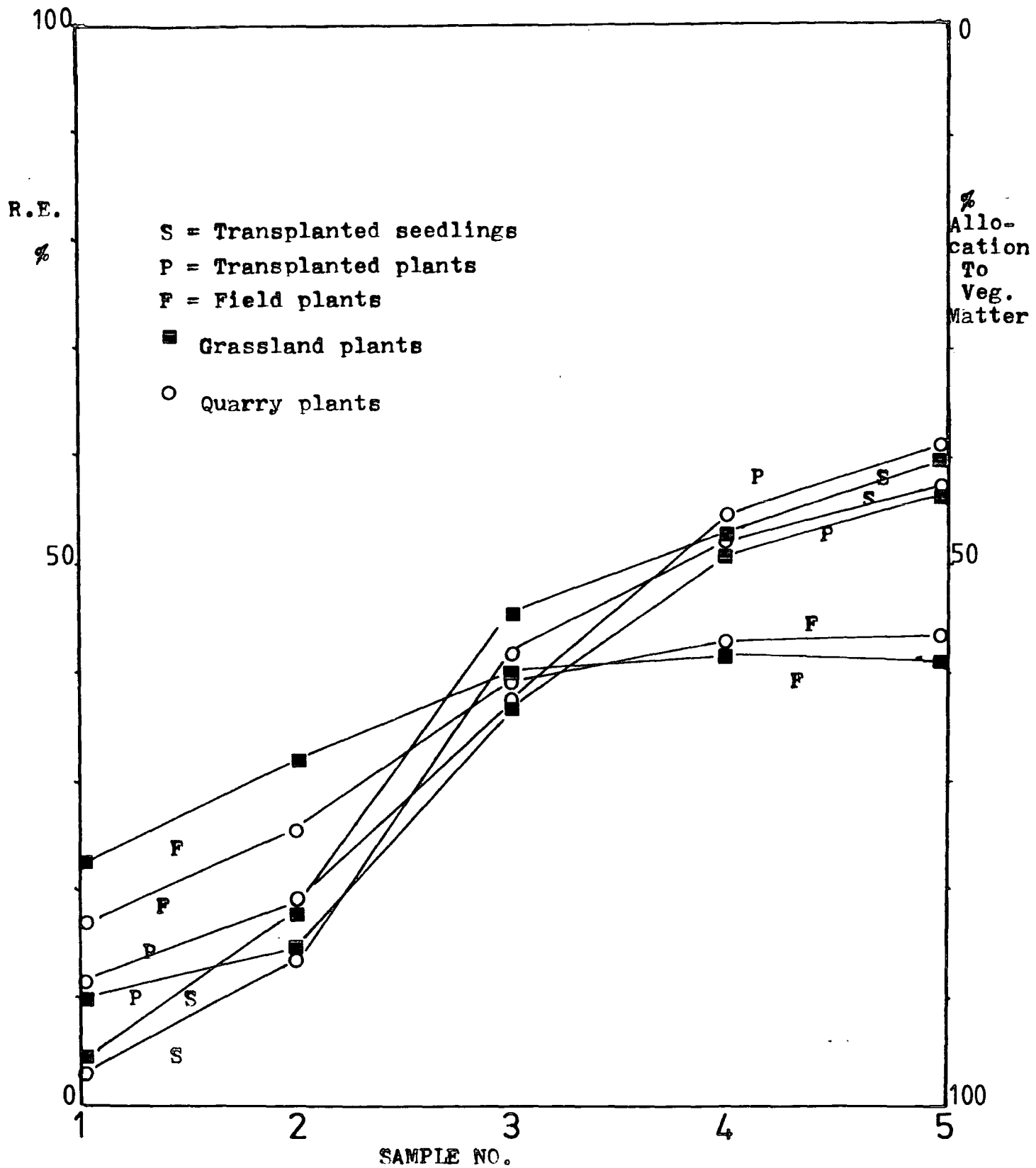
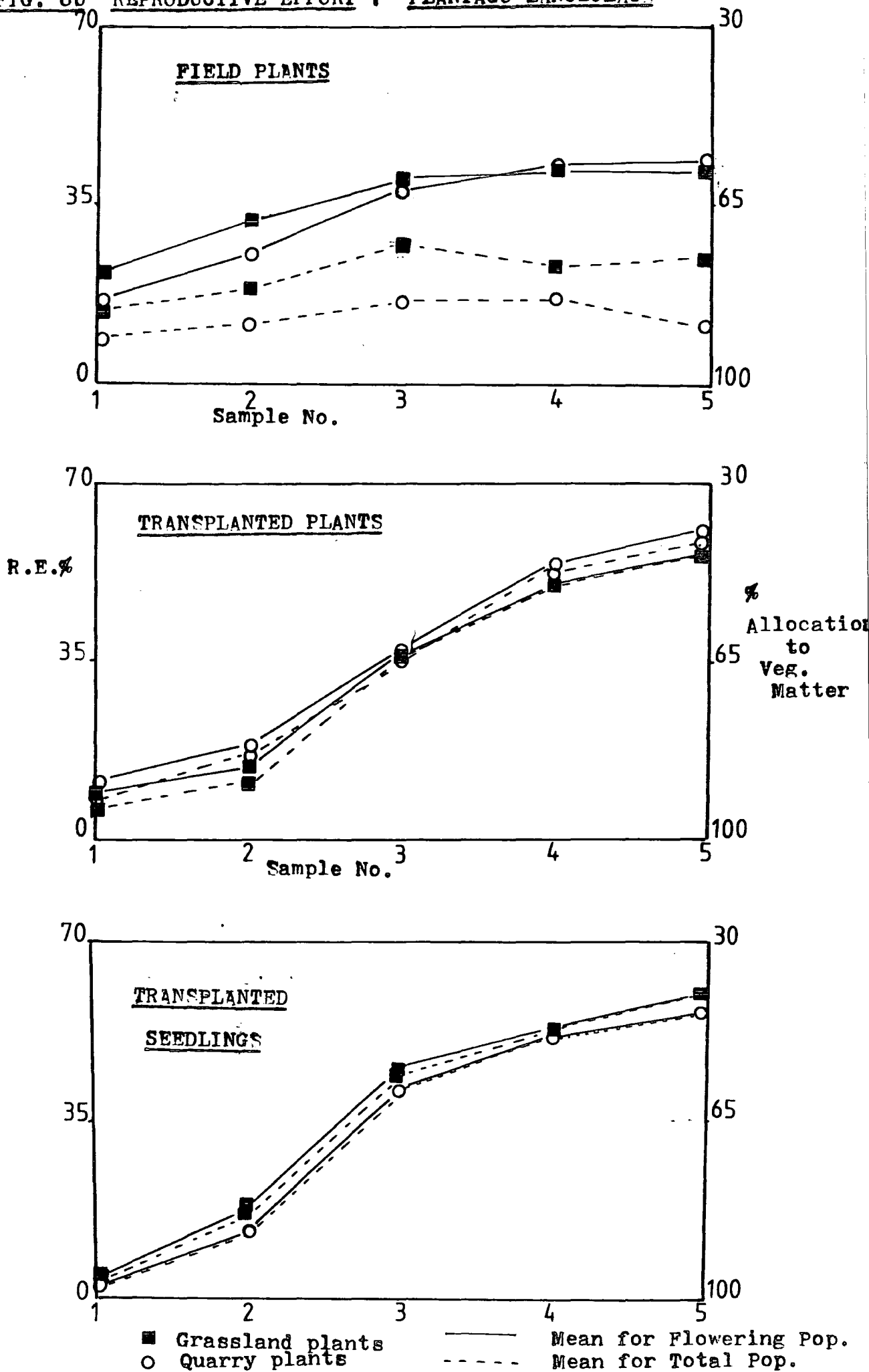


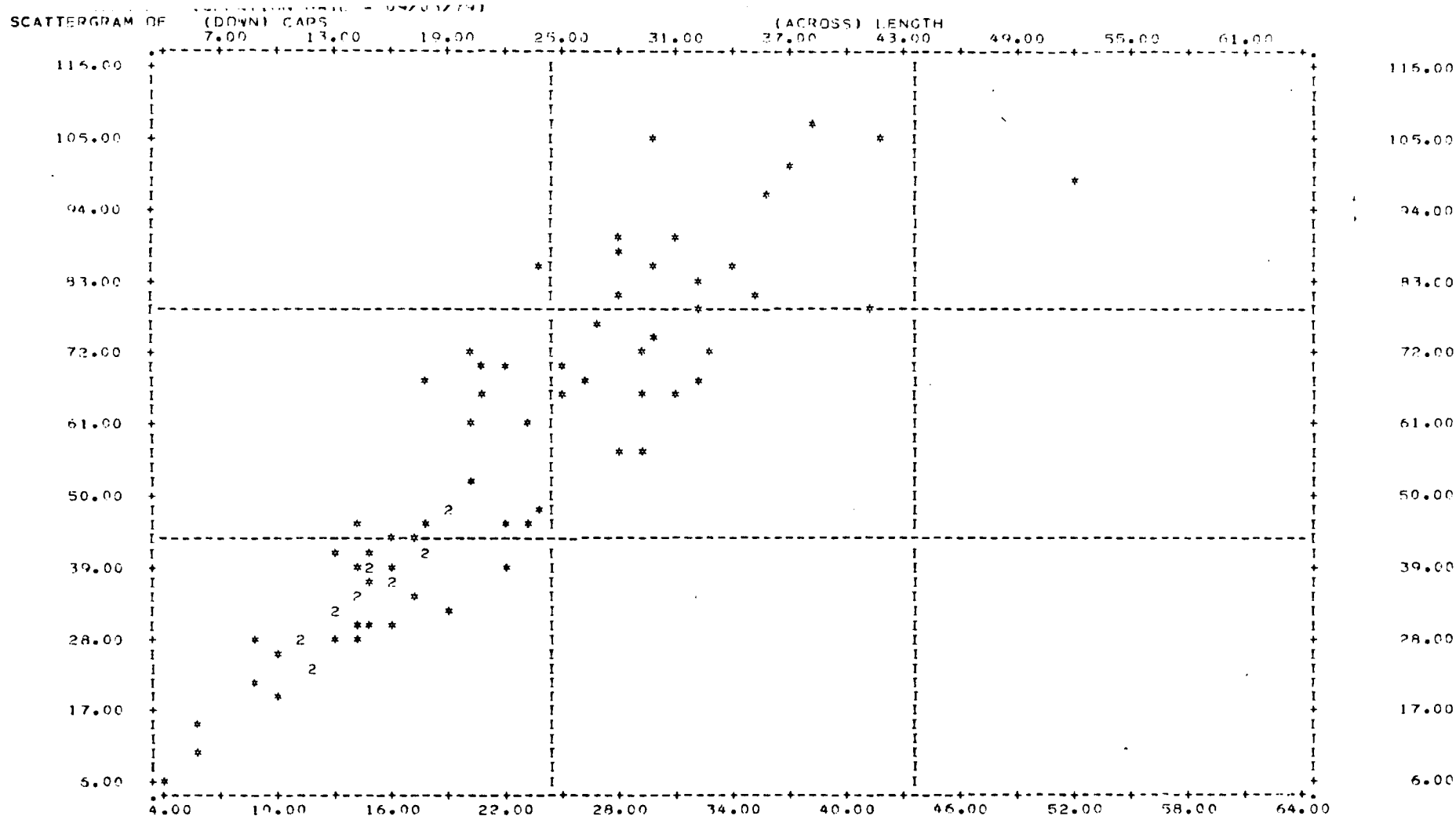
FIG. 8b REPRODUCTIVE EFFORT : *PLANTAGO LANCEOLATA*



of the flower or fruit to seed number. The obvious characteristic in Plantago lanceolata is spike length and a very good straight line regression was produced relating this parameter to capsule number (see fig 9). Plantago lanceolata produces a number of 2-seeded fruits or capsules which make-up the spike. Hence the number of capsules produced as a direct indication of the number of seeds. The figures obtained for total spike length/plant in the final week were thus converted to mean capsule numbers per plant using this regression. The results are shown in Fig 10 and Table 9. The seedlings have the largest R.E. with a mean of 877.25 capsules per plant. The greenhouse plants have a mean of 708.3 and the field plants 73.65. In both the field plants and seedlings the grassland plants have a greater R.E. but this is only significant in the field ( $P = 0.031$ ). The quarry greenhouse plants have a significantly higher output than the grassland plants ( $P = 0.015$ ). When these figures were converted to number of capsules produced/gram vegetative dry weight as is done by Primack (1979) some interesting changes in the mean allocations occur. Quarry plants in the field have the largest mean no. of capsules per gram vegetative dry weight (311.8) whereas grassland plants in the field have the smallest allocation (198.66). Greenhouse plants and seedlings from both sites have very similar allocations. (see Table 9 Fig 10)

#### iv Germinability

The germinability of the seeds could also differ but the results of the germinability experiment are inconclusive (see Table 10). The only significant results were between grassland seedling seeds in the light and dark 12.25 seeds germinating in the light and 7 in the dark ( $P < 0.01$ ) and between grassland and quarry greenhouse plant seeds in the dark, 10.5 grassland seeds germinating in the dark whilst



**FIG. 9 SCATTERGRAM SHOWING NO. OF SEED CAPSULES PER PLANT WITH LENGTH OF FLOWERING SPIKE : PLANTAGO LANCEOLATA**

SCATTERGRAM OF LENGTH/CAPSULES

09/03/79

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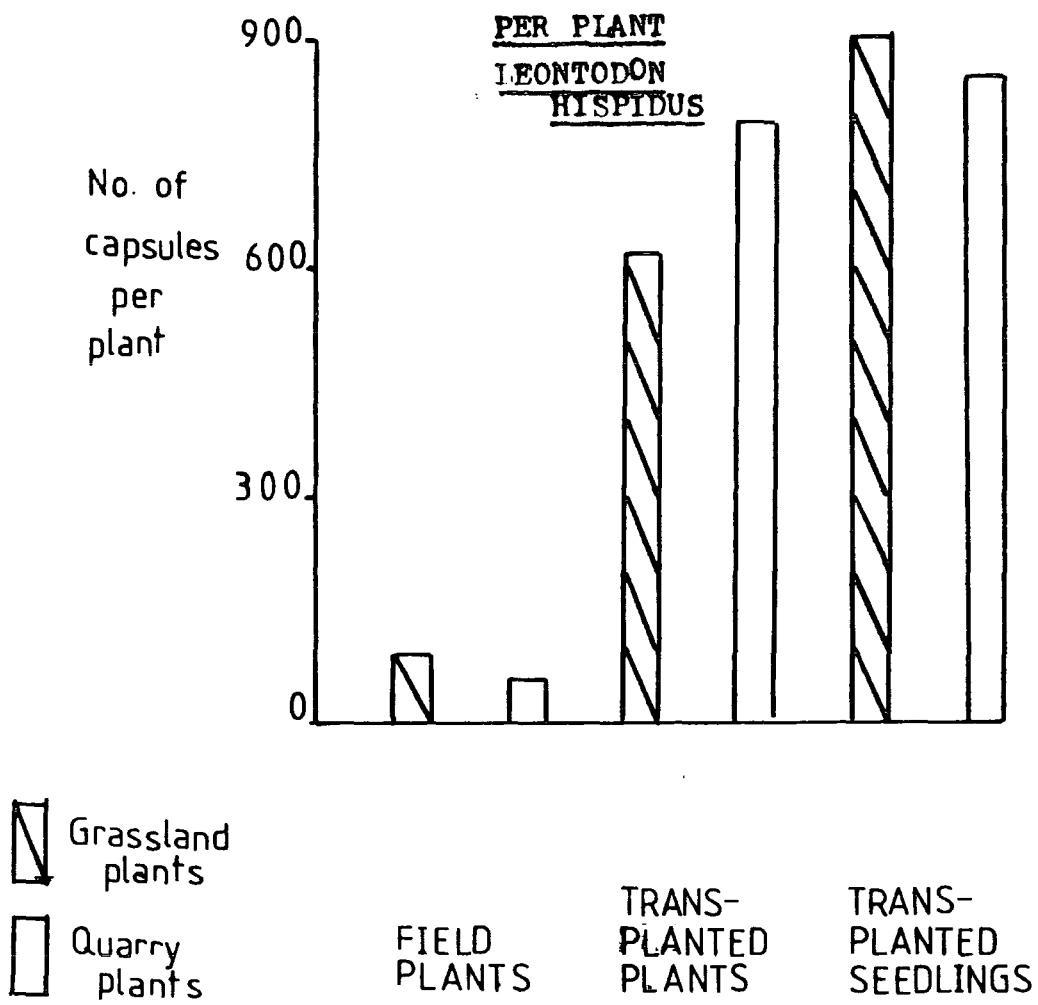
**STATISTICS..**

|   |          |                   |         |                  |         |
|---|----------|-------------------|---------|------------------|---------|
| CORRELATION (R) -                                   | 0.90566  | R SQUARED -       | 0.82023 | SIGNIFICANCE -   | 0.00001 |
| STD ERR OF EST -                                    | 10.61757 | INTERCEPT (A) -   | 2.61725 | SLOPE (B) -      | 2.40235 |
| THE REGRESSION LINE CUTS THE MARGINS OF THE PLOT AT |          |                   |         |                  |         |
| A VALUE OF 12.22663 ON THE LEFT MARGIN              |          |                   |         |                  |         |
| A VALUE OF 48.11246 ON THE TOP MARGIN               |          |                   |         |                  |         |
| PLOTTED VALUES -                                    | 80       | EXCLUDED VALUES - | 0       | MISSING VALUES - | 0       |

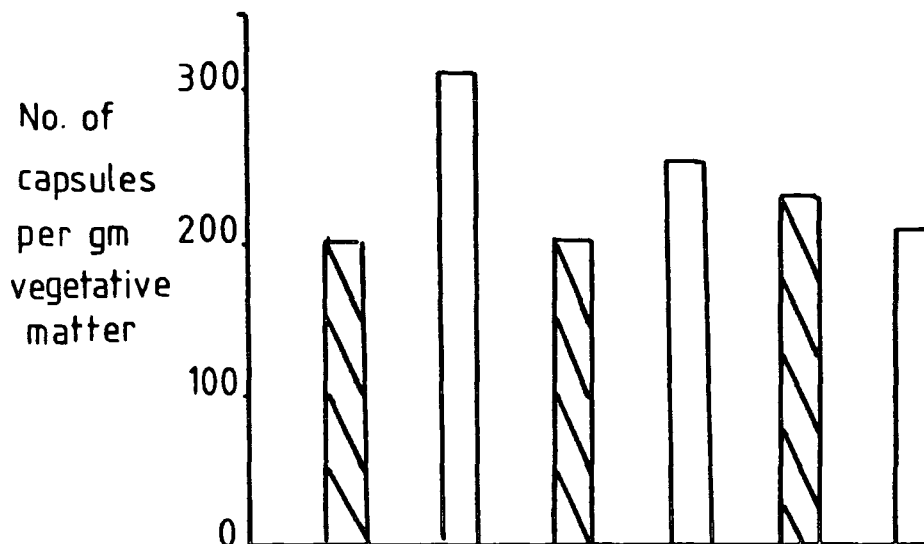
\*\*\*\*\* IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.



**FIG. 10a MEAN NO. OF SEED CAPSULES PRODUCED**



**FIG. 10b**



only 5.75 quarry seeds germinated in the dark. These results were rather inconclusive.

A comparison of the number of vegetative rosettes produced by greenhouse plants was also inconclusive (see Table 9).

### 6.3 Leontodon Hispidus

#### i Weights and Reproductive Effort

The vegetative production of Leontodon hispidus at the 2 sites can be seen in fig 11 and table 11. It is obvious that the quarry plants consistently have a much higher vegetative biomass beginning at 143.2mg plant vegetative dry weight and ending at 202.4mg whilst grassland plants begin at 85.5mg plant vegetative dry weight and end at 140.3mg. The difference between the 2 sites is always significant particularly in the first 3 sample weeks. When this vegetative weight is broken down into its component parts ie number of leaves and diameter (see figs 12 and 13 and Tables 12 and 13) it is immediately evident that this difference is mainly attributable to variations in the number of leaves/plant at each site. At the commencement of sampling each quarry plant has an average of 8.3 leaves whilst grassland plants have 4.9. Even at the end of sampling quarry plants have a mean 8.4 leaves/plant whilst grassland plants have 6.1.

The rate of increase in vegetative biomass over the sampling period is fairly uniform (approx. 15mg/wk.) which contrasts with the rapid increases and fluctuations in reproductive dry weight (see fig 14 and Table 14). At the highest rate of increase quarry plants increase their reproductive dry wt. by 140mg/sample period. Plants were not flowering at either site at the beginning of sampling but quarry plants began in the 2nd week with a mean of 22.9mg/plant and reached 245.8mg/plant in final week. Plants at the grassland site did not begin to devote resources to reproductive production until

FIG. II DRY WEIGHT OF VEGETATIVE MATTER

LEONTODON HISPIDUS

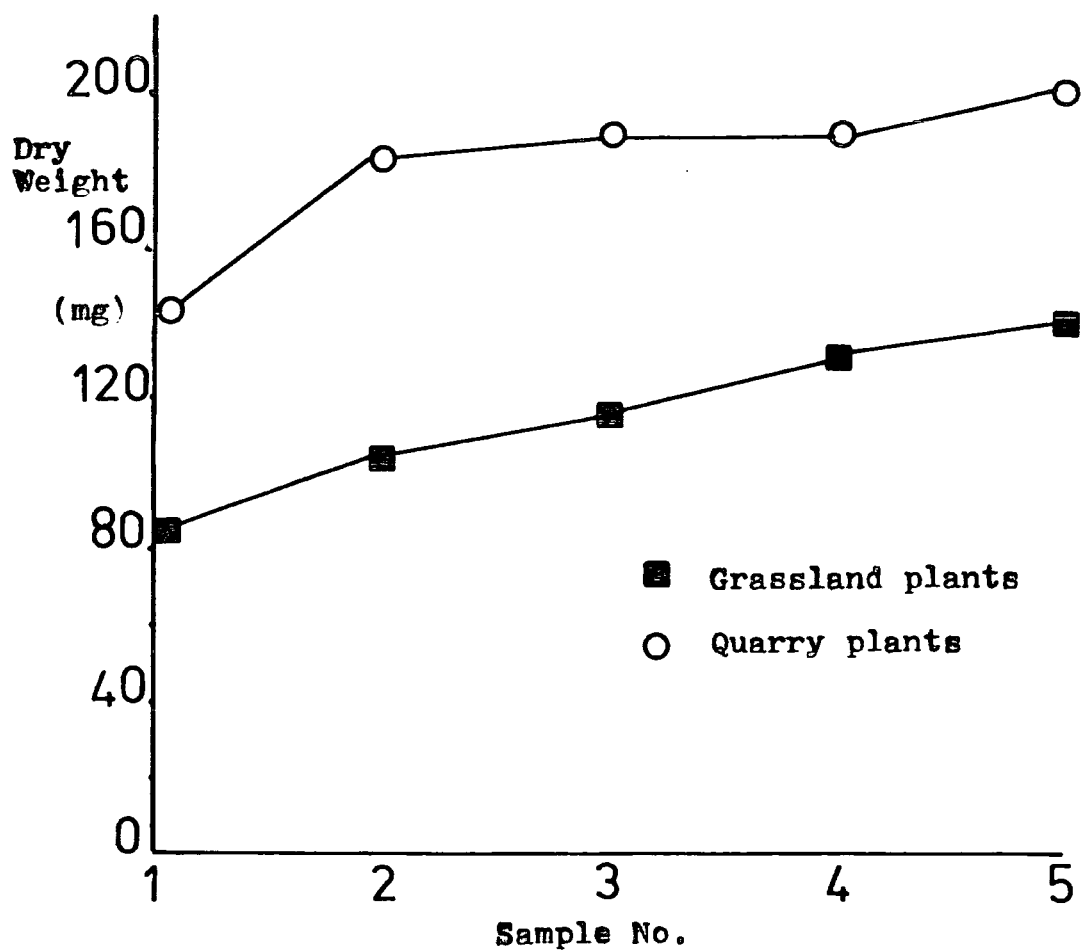
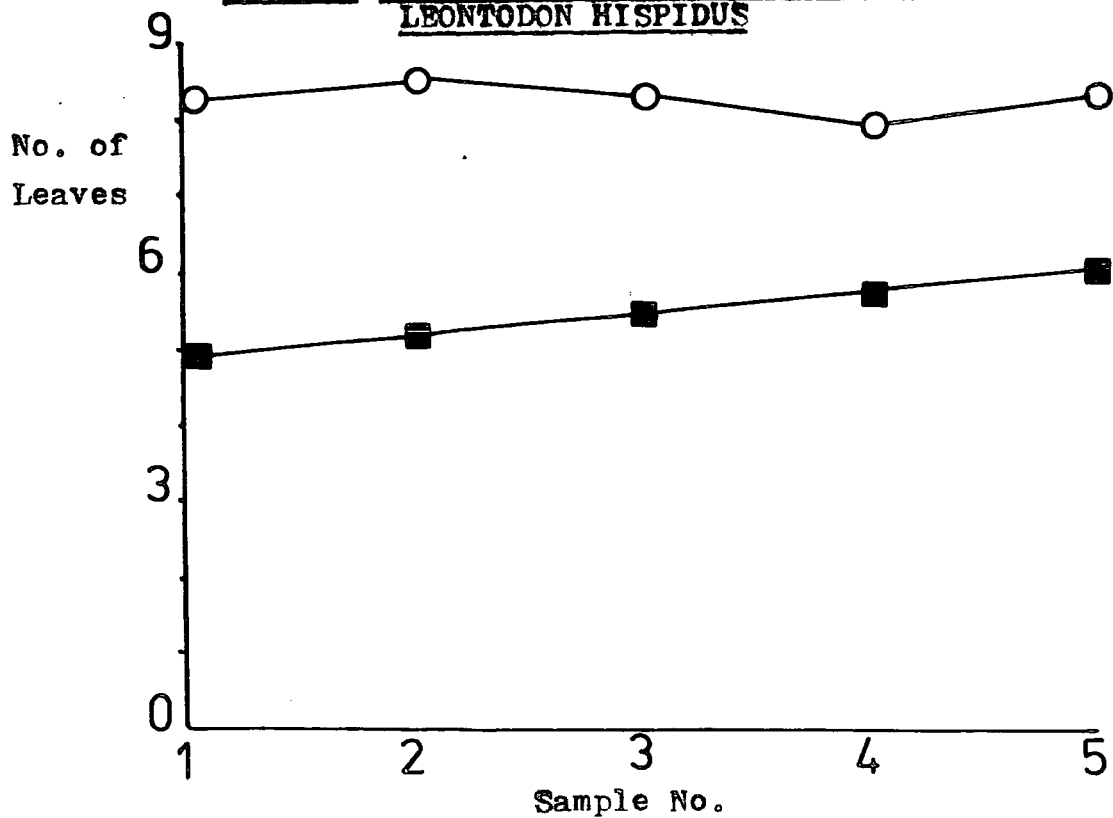
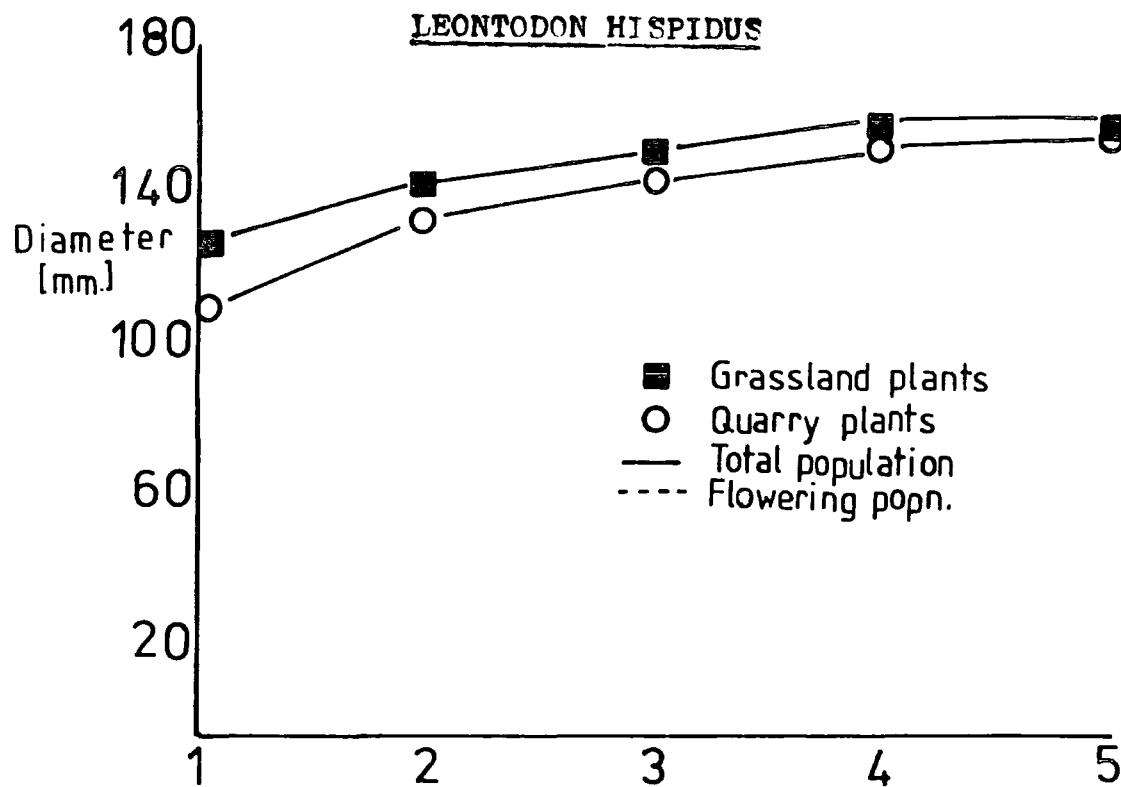


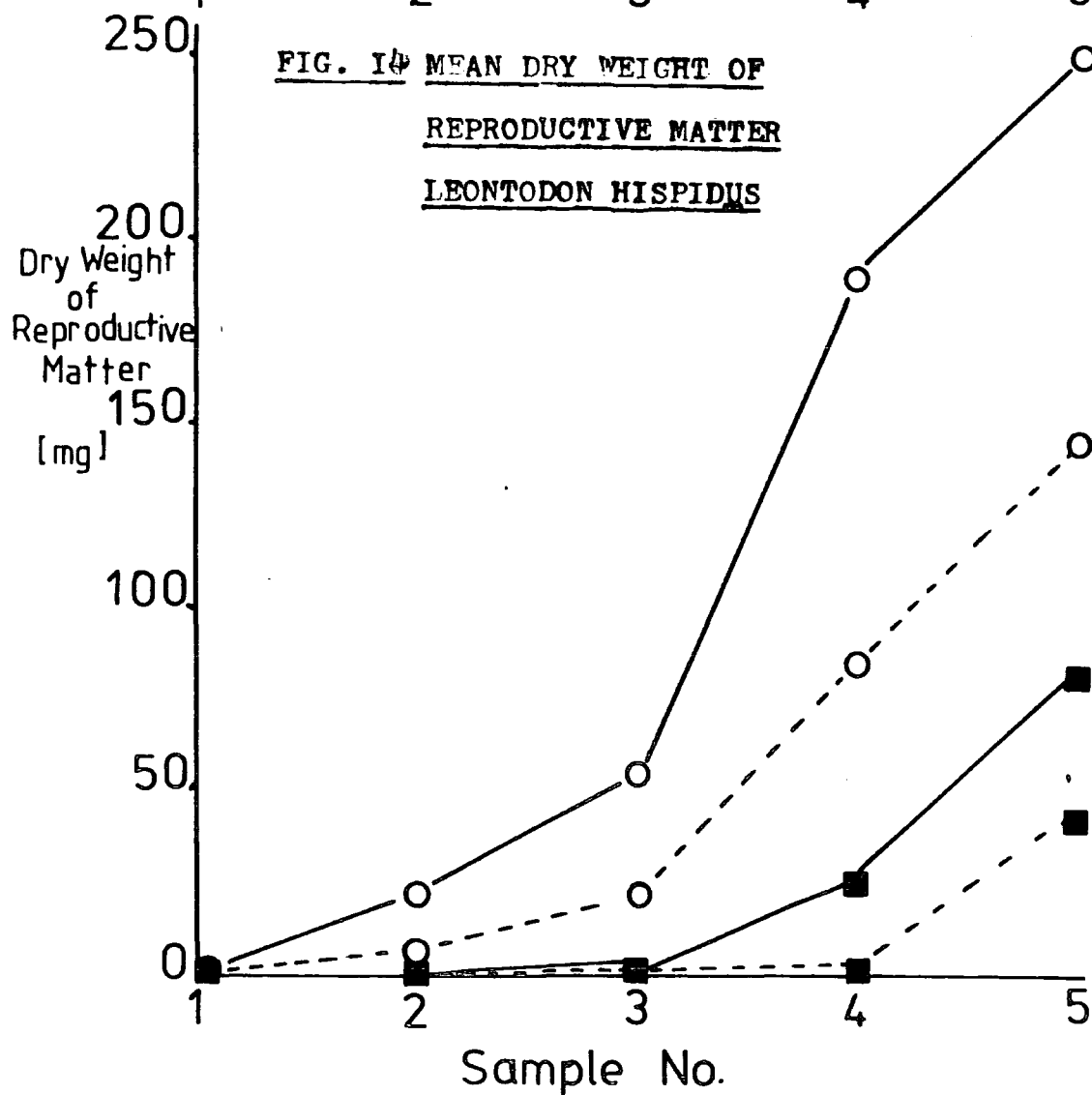
FIG. 12 MEAN. NUMBER OF LEAVES PER PLANT  
LEONTODON HISPIDUS



**FIG. 13 MEAN DIAMETER OF ROSETTES**



**FIG. 14 MEAN DRY WEIGHT OF REPRODUCTIVE MATTER**  
LEONTODON HISPIDUS



the 4th week, with a mean of 27.8mg/flowering plant and reached 82.1mg in the final week. The differences between the 2 sites were therefore significant in the 3rd, 4th and 5th sample weeks. The population reproductive dry weights generally followed the same pattern, but at a lower level since not every plant flowered. They reached maxima of 146.7mg at the quarry site and 40.5mg at the grassland site.

These figures were converted into reproductive efforts and the results can be seen in Fig 15 and Table 15. Quarry flowering plants attain a maximum reproductive effort/plant of 47.1% whilst grassland plants reach 32.2%. It is interesting that the quarry flowering plants appear to lead off to a plateau in the fourth week and this plateau is not so marked in the total population R.E. Again, there is a significant difference between the two sites in the 3rd, 4th and 5th weeks.

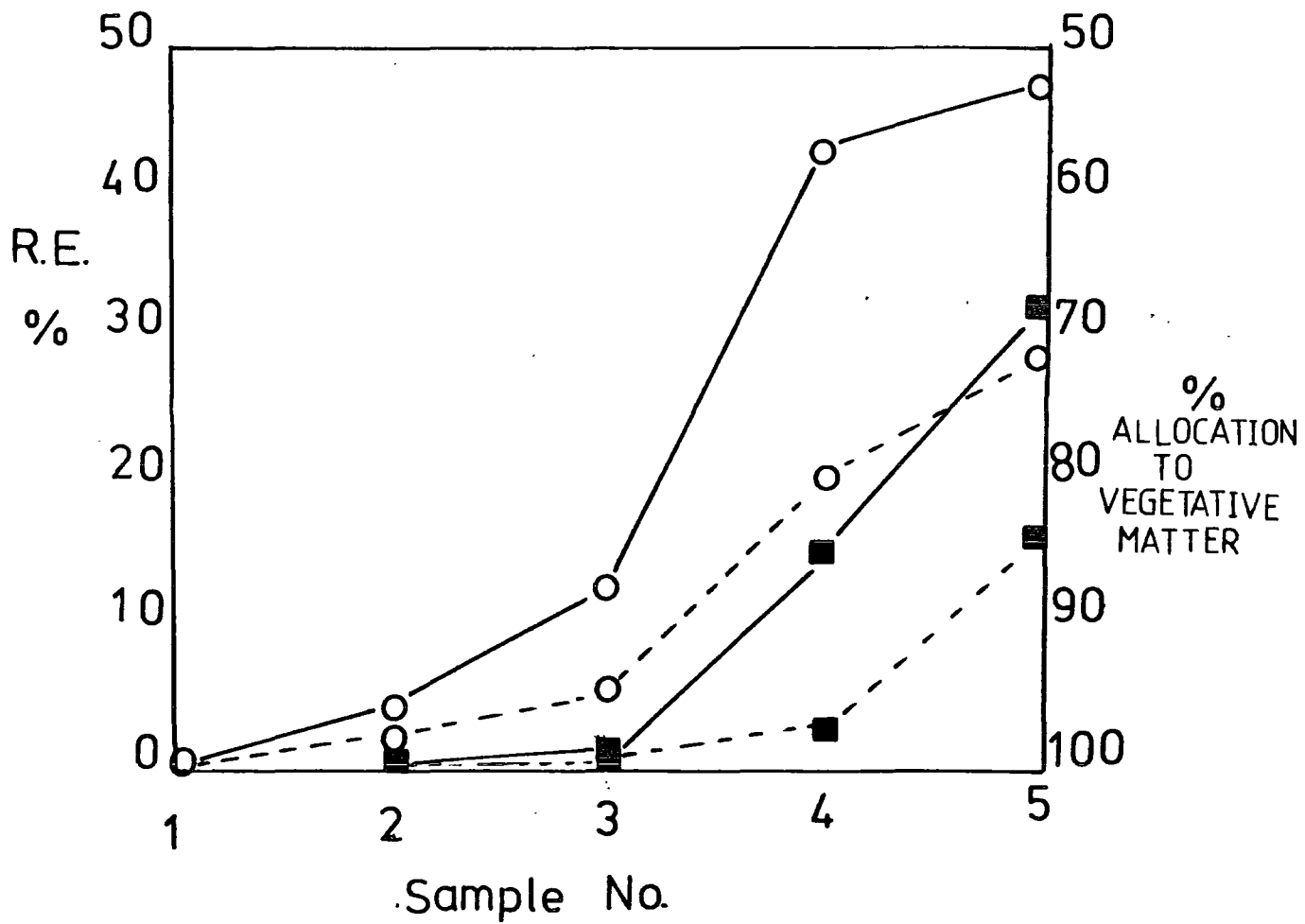
#### ii Mechanisms

Unfortunately, since so many of the Plantago plants in the field were flowering at the beginning of the sample period it was impossible to obtain sufficient plants for statistically valid tests on the mechanisms which determined flowering. Similarly, virtually all the greenhouse and seedling Plantago plants flowered, which rendered an investigation into the possible mechanisms determining flowering impossible. Tests were consequently only possible on data concerning Leontodon hispidus.

Treating quarry and grassland plants separately the flowering and non-flowering plants were separated into two groups and their weights at the beginning of the sample period tested. The difference between the two groups was significant ( $P \leq 0.01$ ) at both sites (see Table 16). Non-flowerers at the quarry site had a lower initial

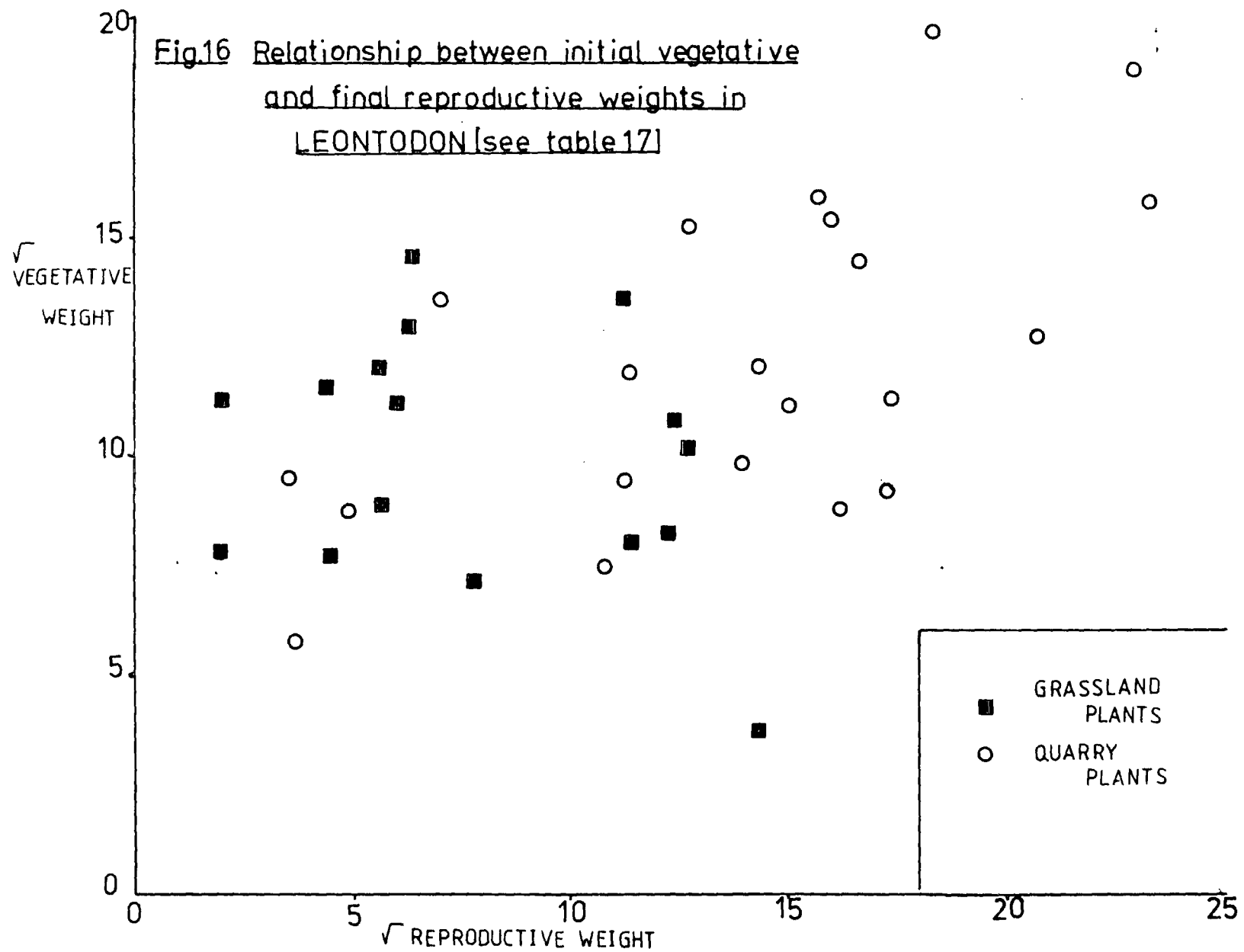
FIG. 15 REPRODUCTIVE EFFORT

LEONTODON HISPIDUS



■ Grassland plants

○ Quarry plants



mean vegetative dry weight ( $7.5^2$ mg) than flowerers ( $12.7^2$ mg). Moreover non-flowerers at the grassland site had a lower initial mean vegetative dry weight ( $7.63^2$ mg) than flowerers ( $10.001$ mg). The quarry flowerers had a significantly higher initial vegetative weight than the grassland flowerers ( $P < 0.05$ ) but the difference between the non-flowerers at each site was not significant.

The quarry flowerers were then further subdivided into those which flowered in the 2nd and 3rd sample weeks and those which flowered in the 4th and fifth sample weeks. Although the earlier flowerers had a higher mean vegetative dry weight ( $13.35^2$ mg), this was not significantly different from the later flowerers ( $11.72^2$ mg). If the grassland plants were included as later flowerers (No grassland plants flowered in the second and third weeks) the difference was significant at the .05 level but it must be remembered that grassland plants were generally smaller than quarry plants (see Table 11).

To test whether initial vegetative dry weight was related to final reproductive dry weight a correlation coefficient was computed (see Table 17 and Fig 16). The correlation between the two was significant at the  $P = < 0.001$  level for the quarry plants but not significant for the grassland plants. When the groups were combined the correlation was again significant at the  $P = < 0.001$  level.



TABLE 4. PLANTAGO DRY WEIGHT OF VEGATIVE BIOMASS (m.g.)

| FIELD PLANTAGO (F) |           |        |        |        |        |        |
|--------------------|-----------|--------|--------|--------|--------|--------|
| Week               |           | wk 1   | wk 2   | wk 3   | wk 4   | wk 5   |
| GRASS              | $\bar{x}$ | 172.1  | 273.3  | 333.9  | 403.4  | 450.8  |
|                    | SD        | 130.5  | 162.5  | 215.8  | 307.5  | 430.8  |
|                    | SE        | 20.9   | 27.1   | 36.5   | 55.2   | 77.4   |
|                    | n         | 39     | 36     | 35     | 31     | 31     |
| QUARRY             | $\bar{x}$ | 91.0   | 173.3  | 186.1  | 199.7  | 185.7  |
|                    | SD        | 71.9   | 94.2   | 93.9   | 134.3  | 116.7  |
|                    | SE        | 11.7   | 15.3   | 14.9   | 21.8   | 18.7   |
|                    | n         | 38     | 38     | 40     | 38     | 39     |
| T-test             | T         | 3.36   | 3.1    | 3.93   | 3.68   | 3.68   |
|                    | df        | 75     | 72     | 73     | 67     | 68     |
|                    | P         | 0.001* | 0.003* | 0.000* | 0.000* | 0.000* |

| GREENHOUSE PLANTS (P) |           |       |        |        |        |        |
|-----------------------|-----------|-------|--------|--------|--------|--------|
| GRASS                 | $\bar{x}$ | 774.2 | 2211.3 | 3101.9 | 3576.2 | 3102.3 |
|                       | SD        | 379   | 1174.9 | 1193.6 | 1446.9 | 1586.7 |
|                       | SE        | 61.6  | 185.8  | 188.7  | 231.7  | 250.9  |
|                       | n         | 38    | 40     | 40     | 39     | 40     |
| QUARRY                | $\bar{x}$ | 522.8 | 1624.1 | 2852.5 | 3715.5 | 3183.4 |
|                       | SD        | 293.5 | 956.1  | 1078.2 | 1377.1 | 1507.2 |
|                       | SE        | 46.4  | 151.2  | 172.6  | 223.4  | 244.5  |
|                       | n         | 40    | 40     | 38     | 38     | 38     |
| T-test                | T         | 3.28  | 2.45   | 0.97   | -0.43  | -0.23  |
|                       | df        | 76    | 78     | 77     | 75     | 76     |
|                       | P         | 0.002 | 0.016  | 0.665  | 0.665  | 0.818  |

| GREENHOUSE SEEDLINGS (S) |           |        |        |        |        |        |
|--------------------------|-----------|--------|--------|--------|--------|--------|
| GRASS                    | $\bar{x}$ | 1377.8 | 3639.5 | 5514.3 | 4985.4 | 3933.1 |
|                          | SD        | 653.9  | 1675.8 | 1857.8 | 2223.1 | 2475.6 |
|                          | SE        | 103.4  | 271.4  | 301.4  | 365.5  | 401.6  |
|                          | n         | 40     | 38     | 38     | 37     | 38     |
| QUARRY                   | $\bar{x}$ | 1286.0 | 3975.7 | 5171.4 | 4947.9 | 4211.4 |
|                          | SD        | 557.7  | 1693.1 | 1645.9 | 2043.3 | 2268.2 |
|                          | SE        | 89.3   | 267.7  | 260.2  | 323.1  | 363.2  |
|                          | n         | 39     | 40     | 40     | 40     | 39     |
| T-test                   | T         | 0.67   | -0.88  | 0.86   | 0.08   | -0.51  |
|                          | df        | 77     | 76     | 76     | 75     | 75     |
|                          | P         | 0.505  | 0.381  | 0.39   | 0.939  | 0.6    |

TABLE 4 (cont.)

\* =  $P < 0.05$

|                                  |   |               |                 |             |
|----------------------------------|---|---------------|-----------------|-------------|
| Difference between F & P in Wk.1 |   |               | GRASS T = 9.2   | $P < 0.001$ |
|                                  |   |               | QUARRY T = 9.0  | $P < 0.001$ |
| "                                | " | P & S in Wk.1 | GRASS T = 5.0   | $P < 0.001$ |
|                                  |   |               | QUARRY T = 7.58 | $P < 0.001$ |
| "                                | " | P & S in Wk.5 | GRASS T = 1.75  | N.S.        |
|                                  |   |               | QUARRY T = 2.34 | $P < 0.05$  |

TABLE 5. PLANTAGO NUMBER OF LEAVES

| <u>FIELD PLANTAGO</u> |           |       |       |       |        |        |
|-----------------------|-----------|-------|-------|-------|--------|--------|
| Week                  |           | Wk.1  | Wk.2  | Wk.3  | Wk.4   | Wk.5   |
| GRASS                 | $\bar{x}$ | 7.7   | 6.8   | 6.7   | 6.9    | 7.2    |
|                       | SD        | 3.2   | 2.2   | 1.8   | 2.8    | 3.6    |
|                       | SE        | 0.5   | 0.4   | 0.3   | 0.5    | 0.6    |
|                       | n         | 39    | 36    | 35    | 31     | 31     |
| QUARRY                | $\bar{x}$ | 6.6   | 6.6   | 6.4   | 5.6    | 5.1    |
|                       | SD        | 2.3   | 2.0   | 1.7   | 1.7    | 1.7    |
|                       | SE        | 0.4   | 0.3   | 0.3   | 0.3    | 0.2    |
|                       | n         | 38    | 38    | 40    | 38     | 39     |
| T-test                | T         | 1.59  | 0.30  | 0.78  | 2.36   | 3.32   |
|                       | df        | 75    | 72    | 73    | 67     | 68     |
|                       | prob      | 0.116 | 0.764 | 0.437 | 0.021* | 0.001* |

| <u>GREENHOUSE PLANTS</u> |           |      |       |       |       |       |
|--------------------------|-----------|------|-------|-------|-------|-------|
| GRASS                    | $\bar{x}$ | 17.6 | 27.8  | 39.8  | 443.3 | 38.9  |
|                          | SD        | 6.8  | 11.2  | 16.1  | 17.7  | 16.1  |
|                          | SE        | 1.1  | 1.8   | 2.6   | 2.8   | 2.6   |
|                          | n         | 38   | 40    | 40    | 39    | 40    |
| QUARRY                   | $\bar{x}$ | 13.0 | 20.6  | 33.6  | 39.7  | 35.1  |
|                          | SD        | 5.2  | 9.0   | 12.7  | 14.5  | 15.2  |
|                          | SE        | 0.8  | 1.4   | 2.0   | 2.4   | 2.5   |
|                          | n         | 40   | 40    | 39    | 38    | 38    |
| T-test                   | T         | 3.36 | 3.15  | 1.89  | 1.24  | 1.08  |
|                          | df        | 76   | 78    | 77    | 75    | 76    |
|                          | prob      | 0.81 | 0.002 | 0.063 | 0.218 | 0.284 |

| <u>GREENHOUSE SEEDLINGS</u> |           |       |       |       |       |       |
|-----------------------------|-----------|-------|-------|-------|-------|-------|
| GRASS                       | $\bar{x}$ | 32.1  | 44.3  | 58.8  | 45.9  | 41.8  |
|                             | SD        | 13.0  | 14.3  | 17.4  | 18.2  | 18.0  |
|                             | SE        | 2.1   | 2.3   | 2.8   | 3.0   | 2.9   |
|                             | n         | 40    | 38    | 38    | 37    | 38    |
| QUARRY                      | $\bar{x}$ | 27.7  | 41.4  | 54.3  | 44.7  | 42.8  |
|                             | SD        | 8.6   | 11.2  | 14.8  | 14.7  | 14.9  |
|                             | SE        | 1.4   | 1.8   | 2.3   | 2.3   | 2.4   |
|                             | n         | 39    | 40    | 40    | 40    | 39    |
| T-test                      | T         | 1.77  | 1.02  | 1.23  | 0.32  | -0.29 |
|                             | df        | 77    | 76    | 76    | 75    | 75    |
|                             | prob      | 0.081 | 0.311 | 0.222 | 0.752 | 0.774 |

\* =  $P < 0.05$

TABLE 6. PLANTAGO PLANT DIAMETER (m.m.)

| FIELD PLANTAGO |           |        |         |        |        |        |
|----------------|-----------|--------|---------|--------|--------|--------|
| Week           |           | Wk.1   | Wk.2    | Wk.3   | Wk.4   | Wk.5   |
| GRASS          | $\bar{x}$ | 174.5  | 212.8   | 240.9  | 269.9  | 275.5  |
|                | SD        | 81.9   | 84.2    | 91.2   | 91.6   | 93.5   |
|                | SE        | 12.9   | 13.8    | 15.4   | 16.4   | 16.8   |
|                | n         | 40     | 37      | 35     | 31     | 31     |
| QUARRY         | $\bar{x}$ | 117.9  | 141.3   | 154.6  | 172.7  | 169.3  |
|                | SD        | 46.0   | 59.0    | 64.4   | 76.5   | 80.3   |
|                | SE        | 7.3    | 9.5     | 10.1   | 12.4   | 12.9   |
|                | n         | 40     | 39      | 40     | 38     | 39     |
| T-test         | T         | 3.81   | 4.31    | 4.77   | 4.8    | 5.11   |
|                | df        | 78     | 74      | 73     | 67     | 68     |
|                | prob      | 0.000* | 0.0000* | 0.000* | 0.000* | 0.000* |

| GREENHOUSE PLANTS |           |       |       |       |        |       |
|-------------------|-----------|-------|-------|-------|--------|-------|
| GRASS             | $\bar{x}$ | 337.4 | 387.1 | 397.9 | 410.9  | 396.1 |
|                   | SD        | 66.7  | 83.5  | 70.4  | 67.9   | 103.9 |
|                   | SE        | 10.5  | 13.2  | 11.1  | 10.7   | 16.4  |
|                   | n         | 40    | 40    | 40    | 40     | 40    |
| QUARRY            | $\bar{x}$ | 301.3 | 371.7 | 425.1 | 473.1  | 451.7 |
|                   | SD        | 72.2  | 71.7  | 61.8  | 83.3   | 92.7  |
|                   | SE        | 11.4  | 11.3  | 9.9   | 13.5   | 14.8  |
|                   | n         | 40    | 40    | 39    | 38     | 38    |
| T-test            | T         | 2.33* | 0.88  | -1.82 | -3.62  | -2.51 |
|                   | df        | 78    | 78    | 77    | 76     | 77    |
|                   | prob      | 0.023 | 0.38  | 0.072 | 0.001* | 0.014 |

| GREENHOUSE SEEDLINGS |           |       |        |       |       |       |
|----------------------|-----------|-------|--------|-------|-------|-------|
| GRASS                | $\bar{x}$ | 326.0 | 397.5  | 472.9 | 543.5 | 448.2 |
|                      | SD        | 52.2  | 52.9   | 71.0  | 108.6 | 115.7 |
|                      | SE        | 8.2   | 8.5    | 11.5  | 17.6  | 18.8  |
|                      | n         | 40    | 39     | 38    | 38    | 38    |
| QUARRY               | $\bar{x}$ | 351.1 | 429.3  | 481.8 | 554.6 | 478.4 |
|                      | SD        | 67.3  | 54.9   | 71.5  | 110.8 | 141.1 |
|                      | SE        | 10.6  | 8.7    | 11.3  | 17.5  | 22.6  |
|                      | n         | 40    | 40     | 40    | 40    | 39    |
| T-test               | T         | -1.86 | -2.62  | -0.55 | -0.45 | -1.03 |
|                      | df        | 78    | 77     | 76    | 76    | 75    |
|                      | prob      | 0.066 | 0.011* | 0.582 | 0.654 | 0.939 |

\* =  $P < 0.05$

TABLE 7a DRY WEIGHT OF REPRODUCTIVE BIOMASS. PLANTAGO  
FLOWERING POPULATION

| <u>FIELD PLANTAGO (F)</u> |           |       |        |        |        |        |
|---------------------------|-----------|-------|--------|--------|--------|--------|
| Week                      |           | Wk.1  | Wk.2   | Wk.3   | Wk.4   | Wk.5   |
| GRASS                     | $\bar{x}$ | 41.3  | 184.0  | 288.4  | 332.4  | 387.4  |
|                           | SD        | 32.6  | 166.0  | 222.1  | 265.0  | 305.7  |
|                           | SE        | 5.6   | 29.4   | 40.6   | 54.1   | 62.4   |
|                           | n         | 34    | 32     | 30     | 24     | 24     |
| QUARRY                    | $\bar{x}$ | 22.7  | 107.1  | 177.8  | 196.2  | 211.9  |
|                           | SD        | 19.7  | 110.8  | 149.8  | 184.8  | 186.4  |
|                           | SE        | 3.5   | 19.9   | 26.5   | 34.3   | 35.2   |
|                           | n         | 31    | 31     | 32     | 29     | 28     |
| T-test                    | T         | 2.75  | 2.15   | 2.31   | 2.2    | 2.54   |
|                           | df        | 63    | 61     | 60     | 51     | 50     |
|                           | prob      | 0.008 | 0.035* | 0.024* | 0.032* | 0.014* |

Difference (G)T = 2.33 P < .01  
between F & P (Q)T = 4.52 P < .001

G. T = 12.29 P < .001  
Q. T = 18.18 P < .001

| <u>GREENHOUSE PLANTS (P)</u> |           |       |       |        |        |        |
|------------------------------|-----------|-------|-------|--------|--------|--------|
| GRASS                        | $\bar{x}$ | 67.7  | 334.6 | 1844.6 | 3891.8 | 4133.1 |
|                              | SD        | 51.2  | 308.9 | 862.5  | 1807.6 | 1885.7 |
|                              | SE        | 9.8   | 52.9  | 138.1  | 285.8  | 298.2  |
|                              | n         | 27    | 34    | 39     | 40     | 40     |
| QUARRY                       | $\bar{x}$ | 71.5  | 411.4 | 1808.7 | 4419.4 | 4831.7 |
|                              | SD        | 57.6  | 416.3 | 1054.2 | 1474.6 | 1551.2 |
|                              | SE        | 10.2  | 67.5  | 171.0  | 242.4  | 251.6  |
|                              | n         | 32    | 38    | 38     | 37     | 38     |
| T-test                       | T         | -0.27 | -0.88 | 0.16   | -1.40  | -1.78  |
|                              | df        | 57    | 70    | 75     | 75     | 76     |
|                              | prob      | 0.792 | 0.382 | 0.870  | 0.167  | 0.079  |

Difference G. T = 1.02 = NS  
between P & S Q. T = 2.63 = P < .01

G. T = 3.45 = P < .001  
Q. T = 1.66 = NS

| <u>GREENHOUSE SEEDLINGS (S)</u> |           |       |       |        |        |        |
|---------------------------------|-----------|-------|-------|--------|--------|--------|
| GRASS                           | $\bar{x}$ | 56.0  | 821.6 | 4554.1 | 5704.7 | 5745.7 |
|                                 | SD        | 34.2  | 570.4 | 1671.0 | 2127.3 | 2214.9 |
|                                 | SE        | 5.9   | 93.8  | 274.7  | 345.1  | 359.3  |
|                                 | n         | 33    | 37    | 37     | 38     | 38     |
| QUARRY                          | $\bar{x}$ | 40.3  | 680.0 | 3866.9 | 5658.3 | 5700.5 |
|                                 | SD        | 935.8 | 567.2 | 1990.2 | 2871.6 | 2862.3 |
|                                 | SE        | 6.0   | 90.8  | 314.7  | 454.0  | 458.3  |
|                                 | n         | 35    | 39    | 40     | 40     | 39     |

TABLE 7b. DRY WEIGHT OF REPRODUCTIVE BIOMASS PLANTAGO  
TOTAL POPULATION

| <u>FIELD PLANTAGO</u> |           |        |        |        |       |       |
|-----------------------|-----------|--------|--------|--------|-------|-------|
| Week                  |           | Wk.1   | Wk.2   | Wk.3   | Wk.4  | Wk.5  |
| GRASS                 | $\bar{x}$ | 34.2   | 151.1  | 238.6  | 244.0 | 286.4 |
|                       | SD        | 34.5   | 175.7  | 239.5  | 285.8 | 328.3 |
|                       | SE        | 5.5    | 28.9   | 40.5   | 51.3  | 58.9  |
|                       | n         | 40     | 37     | 35     | 31    | 31    |
| QUARRY                | $\bar{x}$ | 16.2   | 72.9   | 130.3  | 135.6 | 135.3 |
|                       | SD        | 21.1   | 119.8  | 164.7  | 195.0 | 200.1 |
|                       | SE        | 3.3    | 19.2   | 26.0   | 31.6  | 32.0  |
|                       | n         | 40     | 39     | 40     | 38    | 39    |
|                       | T         | 2.81   | 2.28   | 2.31   | 1.87  | 2.38  |
| T-test                | df        | 78     | 74     | 73     | 67    | 68    |
|                       | prob      | 0.006* | 0.026* | 0.024* | 0.066 | 0.02* |

| <u>GREENHOUSE PLANTS</u> |           |       |       |        |        |        |
|--------------------------|-----------|-------|-------|--------|--------|--------|
| GRASS                    | $\bar{x}$ | 43.8  | 275.4 | 1794.5 | 3891.8 | 4133.1 |
|                          | SD        | 54.4  | 317.9 | 908.4  | 1807.6 | 1885.7 |
|                          | SE        | 8.6   | 50.3  | 143.6  | 285.8  | 298.2  |
|                          | n         | 40    | 40    | 40     | 40     | 40     |
| QUARRY                   | $\bar{x}$ | 56.0  | 387.8 | 1758.3 | 4298.9 | 4703.7 |
|                          | SD        | 60.2  | 418.6 | 1086.9 | 1633.3 | 1726.7 |
|                          | SE        | 9.5   | 66.2  | 174.0  | 264.9  | 276.5  |
|                          | n         | 40    | 40    | 39     | 38     | 39     |
|                          | T         | -0.95 | -1.35 | 0.16   | -1.04  | -1.4   |
| T-test                   | df        | 78    | 78    | 77     | 76     | 77     |
|                          | prob      | 0.343 | 0.18  | 0.872  | 0.301  | 0.165  |

| <u>GREENHOUSE SEEDLINGS</u> |           |       |       |        |        |        |
|-----------------------------|-----------|-------|-------|--------|--------|--------|
| GRASS                       | $\bar{x}$ | 45.2  | 776.4 | 4430.1 | 5704.7 | 5745.7 |
|                             | SD        | 39.1  | 389.1 | 1817.0 | 2127.3 | 2214.9 |
|                             | SE        | 6.2   | 94.3  | 294.8  | 345.1  | 359.3  |
|                             | n         | 40    | 39    | 38     | 38     | 38     |
| QUARRY                      | $\bar{x}$ | 34.5  | 661.5 | 3866.9 | 5658.3 | 5700.5 |
|                             | SD        | 36.8  | 572.0 | 1990.2 | 2871.6 | 2862.3 |
|                             | SE        | 5.8   | 90.4  | 314.7  | 454.0  | 458.3  |
|                             | n         | 40    | 40    | 40     | 40     | 39     |
|                             | T         | 1.25  | 0.88  | 1.3    | 0.08   | 0.08   |
| T-test                      | df        | 78    | 77    | 76     | 76     | 75     |
|                             | prob      | 0.214 | 0.382 | 0.196  | 0.936  | 0.939  |

\* =  $P < 0.05$

TABLE 8a. PLANTAGO REPROD. EFFORT. TOTAL POPULATION.

| FIELD PLANTAGOS |           |       |       |       |       |       |
|-----------------|-----------|-------|-------|-------|-------|-------|
| Week            |           | Wk1.  | Wk.2  | Wk.3  | Wk.4  | Wk.5  |
| GRASS           | $\bar{x}$ | 22.1  | 31.8  | 39.9  | 41.5  | 41.4  |
|                 | SD        | 16.1  | 21.1  | 19.2  | 15.5  | 24.4  |
|                 | SE        | 2.8   | 3.8   | 3.5   | 3.2   | 5.0   |
|                 | n         | 33    | 31    | 30    | 24    | 24    |
| QUARRY          | $\bar{x}$ | 16.4  | 25.4  | 39.4  | 42.6  | 43.6  |
|                 | SD        | 8.4   | 27.6  | 21.2  | 17.0  | 27.0  |
|                 | SE        | 1.6   | 5.0   | 3.7   | 3.2   | 5.1   |
|                 | n         | 29    | 30    | 32    | 29    | 28    |
| T-test          | T         | 1.74  | 1.02  | 0.08  | 0.24  | 0.31  |
|                 | df        | 60    | 59    | 60    | 51    | 50    |
|                 | prob      | 0.087 | 0.311 | 0.936 | 0.814 | 0.761 |

G. T = 4.01  $P < 0.001^*$ Q. T = 2.63  $P < 0.01^*$ G. T = 2.59  $P < 0.01^*$ Q. T = 3.13  $P < 0.001^*$ 

| GREENHOUSE PLANTS |           |       |       |       |       |       |
|-------------------|-----------|-------|-------|-------|-------|-------|
| GRASS             | $\bar{x}$ | 9.6   | 14.9  | 37.3  | 50.7  | 56.5  |
|                   | SD        | 6.8   | 13.9  | 16.0  | 16.6  | 19.0  |
|                   | SE        | 1.4   | 2.4   | 2.6   | 2.7   | 3.0   |
|                   | n         | 25    | 34    | 39    | 39    | 40    |
| QUARRY            | $\bar{x}$ | 11.4  | 18.7  | 37.4  | 54.6  | 61.3  |
|                   | SD        | 6.1   | 15.4  | 13.9  | 12.2  | 14.8  |
|                   | SE        | 1.1   | 2.5   | 2.3   | 2.0   | 2.4   |
|                   | n         | 32    | 38    | 38    | 37    | 37    |
| T-test            | T         | -1.05 | -1.07 | -0.01 | -1.18 | -1.24 |
|                   | df        | 55    | 70    | 75    | 74    | 75    |
|                   | prob      | 0.03  | 0.289 | 0.995 | 0.243 | 0.218 |

G. T = 2.68  $P < 0.01^*$ Q. T = 7.6  $P < 0.001^*$ 

G. T = 0.76 = NS

Q. T = 1.04 = NS

| GREENHOUSE SEEDLINGS |           |       |       |       |       |       |
|----------------------|-----------|-------|-------|-------|-------|-------|
| GRASS                | $\bar{x}$ | 4.0   | 18.0  | 45.5  | 53.3  | 60.0  |
|                      | SD        | 2.8   | 11.6  | 11.8  | 18.2  | 20.1  |
|                      | SE        | 0.5   | 1.9   | 1.9   | 3.0   | 3.3   |
|                      | n         | 33    | 36    | 37    | 37    | 38    |
| QUARRY               | $\bar{x}$ | 2.8   | 13.6  | 41.8  | 52.3  | 56.8  |
|                      | SD        | 2.0   | 8.9   | 14.1  | 19.6  | 22.3  |
|                      | SE        | 0.3   | 1.4   | 2.2   | 3.1   | 3.6   |
|                      | n         | 34    | 39    | 40    | 40    | 39    |
| T-test               | T         | 1.88  | 1.85  | 1.26  | 0.23  | 0.66  |
|                      | df        | 65    | 73    | 75    | 75    | 75    |
|                      | prob      | 0.064 | 0.068 | 0.212 | 0.818 | 0.512 |

\* =  $P < 0.05$

TABLE 8b. PLANTAGO REPRODUCTIVE EFFORT.  
FLOWERING POPULATION

| <u>FIELD PLANTAGO</u> |           |       |       |       |       |       |
|-----------------------|-----------|-------|-------|-------|-------|-------|
| Week                  |           | Wk.1  | Wk.2  | Wk.3  | Wk.4  | Wk.5  |
| GRASS                 | $\bar{x}$ | 14.7  | 19.0  | 27.1  | 23.2  | 24.9  |
|                       | SD        | 28.6  | 39.6  | 38.1  | 39.2  | 38.7  |
|                       | SE        | 4.6   | 6.6   | 6.4   | 7.0   | 6.9   |
|                       | n         | 39    | 36    | 35    | 31    | 31    |
| QUARRY                | $\bar{x}$ | 8.9   | 11.9  | 15.9  | 16.2  | 11.4  |
|                       | SD        | 15.9  | 53.6  | 52.3  | 52.3  | 58.4  |
|                       | SE        | 2.6   | 8.7   | 8.3   | 8.5   | 9.4   |
|                       | n         | 38    | 38    | 40    | 38    | 39    |
| T-test                | T         | 1.1   | 1.55  | 1.04  | 0.62  | 1.11  |
|                       | df        | 75    | 72    | 73    | 67    | 68    |
|                       | prob      | 0.274 | 0.126 | 0.304 | 0.536 | 0.271 |

|                |    |               |    |          |           |
|----------------|----|---------------|----|----------|-----------|
| Difference     | G. | T = 1.81 = NS | G. | T = 4.17 | P = 0.001 |
| between F & P. | Q. | T = 0.07 = NS | Q. | T = 4.92 | P = 0.001 |

| <u>GREENHOUSE PLANTS</u> |           |       |       |       |       |       |
|--------------------------|-----------|-------|-------|-------|-------|-------|
| GRASS                    | $\bar{x}$ | 6.1   | 11.8  | 36.1  | 50.7  | 56.5  |
|                          | SD        | 7.4   | 15.2  | 17.7  | 16.6  | 19.0  |
|                          | SE        | 1.2   | 2.4   | 2.8   | 2.6   | 3.0   |
|                          | n         | 38    | 40    | 40    | 39    | 40    |
| QUARRY                   | $\bar{x}$ | 8.7   | 17.2  | 36.2  | 53.1  | 59.6  |
|                          | SD        | 7.7   | 16.3  | 15.5  | 15.2  | 17.9  |
|                          | SE        | 1.2   | 2.6   | 2.5   | 2.5   | 2.9   |
|                          | n         | 40    | 40    | 39    | 38    | 38    |
| T-test                   | T         | -1.55 | -1.53 | -0.04 | -0.67 | -0.76 |
|                          | df        | 76    | 78    | 77    | 75    | 76    |
|                          | prob      | 0.125 | 0.131 | 0.971 | 0.506 | 0.451 |

| <u>GREENHOUSE SEEDLINGS</u> |           |       |       |       |       |       |
|-----------------------------|-----------|-------|-------|-------|-------|-------|
| GRASS                       | $\bar{x}$ | 3.1   | 16.9  | 44.3  | 53.3  | 60.0  |
|                             | SD        | 3.2   | 12.2  | 13.9  | 18.2  | 20.1  |
|                             | SE        | 0.5   | 2.0   | 2.3   | 3.0   | 3.3   |
|                             | n         | 40    | 38    |       | 37    | 38    |
| QUARRY                      | $\bar{x}$ | 2.4   | 13.2  | 41.8  | 52.3  | 56.8  |
|                             | SD        | 2.2   | 9.1   | 14.1  | 19.6  | 22.3  |
|                             | SE        | 0.3   | 1.4   | 2.2   | 3.1   | 3.6   |
|                             | n         | 38    | 40    |       | 40    | 39    |
| T-test                      | T         | 1.15  | 1.53  | 0.79  | 0.23  | 0.66  |
|                             | df        | 77    | 76    | 76    | 75    | 75    |
|                             | prob      | 0.255 | 0.131 | 0.432 | 0.818 | 0.512 |



TABLE 9. NO. OF 2-SEEDED CAPSULES/PLANT,  
1gm. VEGETATIVE WEIGHT AND NO. OF VEGETATIVE ROSETTES/PLANT.

| FIELD PLANTAGO |           |                     |                 |                              |
|----------------|-----------|---------------------|-----------------|------------------------------|
|                |           | <u>Total length</u> | <u>Capsules</u> | <u>x caps/gm<br/>veg.wt.</u> |
| GRASS          | $\bar{x}$ | 36.1                | 89.4            | 198.66                       |
|                | SD        | 25.0                | 60.1            | 139.507                      |
|                | SE        | 5.1                 | 12.3            | 28.47                        |
|                | n         | 24                  | 24              | 24                           |
| QUARRY         | $\bar{x}$ | 23.0                | 57.9            | 311.79                       |
|                | SD        | 16.0                | 38.5            | 329.9                        |
|                | SE        | 3.1                 | 7.6             | 64.6                         |
|                | n         | 26                  | 26              | 26                           |
| T-test         | T         | 2.22                | 2.22            | 1.6                          |
|                | df        | 48                  | 48              | 48                           |
|                | prob      | 0.031*              | 0.031*          | NS                           |

| GREENHOUSE PLANTS |           |        |        |         |
|-------------------|-----------|--------|--------|---------|
| GRASS             | $\bar{x}$ | 257.8  | 621.9  | 200.464 |
|                   | SD        | 172.0  | 269.1  | 169.59  |
|                   | SE        | 17.7   | 42.5   | 26.8    |
|                   | n         | 40     | 40     | 40      |
| QUARRY            | $\bar{x}$ | 329.7  | 794.7  | 249.638 |
|                   | SD        | 139.7  | 335.6  | 222.66  |
|                   | SE        | 22.9   | 55.2   | 36.6    |
|                   | n         | 37     | 37     | 37      |
| T-test            | T         | -2.5   | -2.5   | 1.08    |
|                   | df        | 75     | 75     | 75      |
|                   | prob      | 0.015* | 0.015* | NS      |

| GREENHOUSE SEEDLINGS |           |                     |                 |                              |  |
|----------------------|-----------|---------------------|-----------------|------------------------------|--|
|                      |           | <u>Total length</u> | <u>Capsules</u> | <u>x caps/gm<br/>veg.wt.</u> | <u>No.of vegetative<br/>rosettes/plant</u> |
| GRASS                | $\bar{x}$ | 373.9               | 900.9           | 229.055                      | 5.0  |
|                      | SD        | 176.6               | 424.2           | 171.3                        | 1.6  |
|                      | SE        | 27.9                | 67.1            | 27.08                        | 0.3  |
|                      | n         | 40                  | 40              | 40                           | 39   |
| QUARRY               | $\bar{x}$ | 354.2               | 853.6           | 202.68                       | 4.6  |
|                      | SD        | 167.5               | 402.3           | 177.38                       | 1.5  |
|                      | SE        | 26.5                | 63.6            | 28.04                        | 0.2  |
|                      | n         | 40                  | 40              | 40                           | 40   |
| T-test               | T         | 0.51                | 0.51            | 0.67                         | 1.22                                       |
|                      | df        | 78                  | 78              | 78                           | 77   |
|                      | prob      | 0.610               | 0.610           | NS                           | 0.225                                      |

\* =  $P < 0.05$

TABLE 10. NUMBERS OF GERMINATING SEEDS IN VARIOUS CONDITIONS.

| <u>FIELD PLANTAGO</u> |           |              |             |              |
|-----------------------|-----------|--------------|-------------|--------------|
|                       |           | <u>Light</u> | <u>Dark</u> |              |
| GRASS                 | $\bar{x}$ | 5.25         | 4.0         |              |
|                       | SD        | 2.5          | 1.4         | T = 0.87     |
|                       | SE        | 1.25         | 0.707       | df = 6       |
|                       | n         | 4            | 4           | prob = 0.418 |
| QUARRY                | $\bar{x}$ | 7.25         | 5.25        |              |
|                       | SD        | 0.96         | 2.2         | T = 1.66     |
|                       | SE        | 0.47         | 1.109       | df = 6       |
|                       | n         | 4            | 4           | prob = 0.149 |
| T-test                | T         | -1.49        | -0.95       |              |
|                       | df        | 6            | 6           |              |
|                       | prob      | 0.186        | 0.379       |              |

| <u>GREENHOUSE PLANTS</u> |           |       |       |              |
|--------------------------|-----------|-------|-------|--------------|
|                          |           |       |       |              |
| GRASS                    | $\bar{x}$ | 6.25  | 10.5  |              |
|                          | SD        | 3.403 | 1.732 | T = 2.23     |
|                          | SE        | 1.702 | 0.866 | df = 6       |
|                          | n         | 4     | 4     | prob = 0.068 |
| QUARRY                   | $\bar{x}$ | 7.5   | 5.75  |              |
|                          | SD        | 3.0   | 3.5   | T = 0.76     |
|                          | SE        | 1.5   | 1.75  | df = 6       |
|                          | n         | 4     | 4     | prob = 0.476 |
| T-test                   | T         | -0.55 | 2.43  |              |
|                          | df        | 6     | 6     |              |
|                          | prob      | 0.602 | 0.051 |              |

| <u>GREENHOUSE SEEDLINGS</u> |           |       |       |              |
|-----------------------------|-----------|-------|-------|--------------|
|                             |           |       |       |              |
| GRASS                       | $\bar{x}$ | 12.25 | 7.0   |              |
|                             | SD        | 0.957 | 2.708 | T = 3.66     |
|                             | SE        | 0.479 | 1.354 | df = 6       |
|                             | n         | 4     | 4     | prob = 0.01* |
| QUARRY                      | $\bar{x}$ | 9.75  | 8.0   |              |
|                             | SD        | 4.646 | 1.633 | T = 0.71     |
|                             | SE        | 2.323 | 0.816 | df = 6       |
|                             | n         | 4     | 4     | prob = 0.504 |
| T-test                      | T         | 1.05  | -0.63 |              |
|                             | df        | 6     | 6     |              |
|                             | prob      | 0.332 | 0.55  |              |

\* =  $P < 0.005$

TABLES 11, 12 & 13. LEONTODON HISPIDUS.

| TABLE 11: VEGETATIVE BIOMASS (m.g.) |           |        |        |        |        |        |
|-------------------------------------|-----------|--------|--------|--------|--------|--------|
| Week                                |           | Wk.1   | Wk.2   | Wk.3   | Wk.4   | Wk.5   |
| GRASS                               | $\bar{x}$ | 85.5   | 105.3  | 117.1  | 132.6  | 140.3  |
|                                     | SD        | 47.3   | 51.4   | 49.1   | 53.5   | 61.8   |
|                                     | SE        | 7.5    | 8.1    | 7.8    | 8.8    | 10.4   |
|                                     | n         | 40     | 40     | 40     | 40     | 40     |
| QUARRY                              | $\bar{x}$ | 143.2  | 184.6  | 190.5  | 189.9  | 202.4  |
|                                     | SD        | 123.1  | 164.4  | 152.1  | 147.0  | 149.1  |
|                                     | SE        | 19.5   | 26.0   | 24.0   | 24.2   | 24.5   |
|                                     | n         | 40     | 40     | 40     | 37     | 37     |
| T-test                              | T         | -2.77  | -2.91  | -2.91  | -2.23  | -2.28  |
|                                     | df        | 78     | 78     | 78     | 72     | 70     |
|                                     | prob      | 0.007* | 0.005* | 0.005* | 0.029* | 0.025* |

| TABLE 12: NO. OF LVES. |           |        |        |        |        |        |
|------------------------|-----------|--------|--------|--------|--------|--------|
| GRASS                  | $\bar{x}$ | 4.9    | 5.2    | 5.5    | 5.8    | 6.1    |
|                        | SD        | 1.5    | 1.4    | 1.3    | 1.01   | 1.4    |
|                        | SE        | 0.2    | 0.2    | 0.2    | 0.2    | 0.2    |
|                        | n         | 40     | 40     | 40     | 37     | 35     |
| QUARRY                 | $\bar{x}$ | 8.3    | 8.6    | 8.4    | 8.0    | 8.4    |
|                        | SD        | 3.4    | 3.5    | 2.9    | 2.8    | 3.3    |
|                        | SE        | 0.5    | 0.6    | 0.5    | 0.5    | 0.5    |
|                        | n         | 40     | 40     | 40     | 37     | 37     |
| T-test                 | T         | -5.89  | -5.58  | -5.75  | -4.64  | -3.94  |
|                        | df        | 78     | 78     | 78     | 72     | 70     |
|                        | prob      | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* |

| TABLE 13: DIAMETER (m.m.) |           |       |       |       |       |       |
|---------------------------|-----------|-------|-------|-------|-------|-------|
| GRASS                     | $\bar{x}$ | 129.6 | 146.5 | 155.6 | 162.3 | 161.4 |
|                           | SD        | 39.5  | 40.9  | 48.8  | 44.0  | 44.7  |
|                           | SE        | 6.2   | 6.4   | 7.7   | 7.2   | 7.6   |
|                           | n         | 40    | 40    | 40    | 37    | 35    |
| QUARRY                    | $\bar{x}$ | 111.7 | 135.7 | 146.2 | 155.9 | 159.2 |
|                           | SD        | 53.1  | 64.0  | 66.4  | 68.2  | 68.1  |
|                           | SE        | 8.4   | 10.1  | 10.5  | 11.2  | 11.2  |
|                           | n         | 40    | 40    | 40    | 37    | 37    |
| T-test                    | T         | 1.71  | 0.89  | 0.72  | 0.48  | 0.16  |
|                           | df        | 78    | 78    | 78    | 72    | 70    |
|                           | prob      | 0.09  | 0.374 | 0.473 | 0.633 | 0.874 |

\* =  $P < 0.05$

TABLE 14a. LEONTODON HISPIDUS.

REPRODUCTIVE BIOMASS. (FLOWERING POPULATION. m.g.)

| Week   |           | Wk.1 | Wk.2  | Wk.3   | Wk.4   | Wk.5   |
|--------|-----------|------|-------|--------|--------|--------|
| GRASS  | $\bar{x}$ | 0.0  | 0.0   | 0.0    | 27.8   | 82.1   |
|        | SD        | 0.0  | 0.0   | 0.0    | 24.1   | 68.6   |
|        | SE        | 0.0  | 0.0   | 0.0    | 12.1   | 16.6   |
|        | n         | 0    | 0     | 0      | 4      | 17     |
| QUARRY | $\bar{x}$ | 0.0  | 22.9  | 56.4   | 185.3  | 245.8  |
|        | SD        | 0.0  | 52.0  | 96.1   | 134.2  | 178.4  |
|        | SE        | 0.0  | 16.4  | 24.8   | 32.5   | 38.1   |
|        | n         | 0    | 10    | 15     | 17     | 22     |
| T-test | T         | 0.0  | -1.39 | -2.27  | -2.30  | -3.58  |
|        | df        | 0    | 9     | 14     | 19     | 37     |
|        | prob      | 1.0  | 0.197 | 0.039* | 0.033* | 0.001* |

TABLE 14b. LEONTODON HISPIDUS.

REPRODUCTIVE BIOMASS. (TOTAL POPULATION.)

| Week   |           | Wk.1 | Wk.2  | Wk.3   | Wk.4   | Wk.5   |
|--------|-----------|------|-------|--------|--------|--------|
| GRASS  | $\bar{x}$ | 1.3  | 1.3   | 1.3    | 4.2    | 40.5   |
|        | SD        | 0.0  | 0.0   | 0.0    | 10.8   | 62.4   |
|        | SE        | 0.0  | 0.0   | 0.0    | 1.8    | 10.5   |
|        | n         | 40   | 40    | 40     | 37     | 35     |
| QUARRY | $\bar{x}$ | 1.3  | 6.7   | 21.9   | 85.9   | 146.7  |
|        | SD        | 0.0  | 26.7  | 63.6   | 129.0  | 182.7  |
|        | SE        | 0.0  | 4.2   | 10.1   | 21.2   | 30.0   |
|        | n         | 40   | 40    | 40     | 37     | 37     |
|        | T         | 0.0  | -1.28 | -2.05  | -3.84  | -3.26  |
|        | df        | 78   | 78    | 78     | 72     | 70     |
|        | prob      | 1.0  | 0.205 | 0.043* | 0.000* | 0.002* |

\* =  $P < 0.05$

TABLE 15a. LEONTODON HISPIDUS.REPRODUCTIVE EFFORT. (FLOWERING POPULATION)

| Week   |           | Wk.1 | Wk.2  | Wk.3   | Wk.4   | Wk.5   |
|--------|-----------|------|-------|--------|--------|--------|
| GRASS  | $\bar{x}$ | 0.0  | 0.0   | 0.0    | 15.0   | 32.2   |
|        | SD        | 0.0  | 0.0   | 0.0    | 12.7   | 24.8   |
|        | SE        | 0.0  | 0.0   | 0.0    | 6.4    | 6.0    |
|        | n         | 0    | 0     | 0      | 4      | 17     |
| QUARRY | $\bar{x}$ | 0.0  | 4.6   | 12.8   | 43.1   | 47.1   |
|        | SD        | 0.0  | 6.9   | 10.7   | 20.1   | 21.7   |
|        | SE        | 0.0  | 2.2   | 2.8    | 4.9    | 4.6    |
|        | n         | 0    | 10    | 15     | 17     | 22     |
|        | T         | 0.0  | -2.1  | -4.67  | -2.65  | -2.01  |
|        | df        | 0    | 9     | 14     | 19     | 37     |
|        | prob      | 1.0  | 0.065 | 0.000* | 0.016* | 0.052* |

TABLE 15b. LEONTODON HISPIDUS.REPRODUCTIVE EFFORT. (TOTAL POPULATION)

| Week   |           | Wk.1  | Wk.2  | Wk.3   | Wk.4  | Wk.5   |
|--------|-----------|-------|-------|--------|-------|--------|
| GRASS  | $\bar{x}$ | 2.1   | 1.5   | 1.4    | 2.7   | 16.3   |
|        | SD        | 1.6   | 0.8   | 1.0    | 5.7   | 23.1   |
|        | SE        | 0.3   | 0.1   | 0.2    | 0.9   | 3.9    |
|        | n         | 40    | 40    | 40     | 37    | 35     |
| QUARRY | $\bar{x}$ | 1.8   | 2.5   | 5.7    | 20.5  | 28.6   |
|        | SD        | 1.6   | 3.9   | 8.5    | 25.0  | 28.2   |
|        | SE        | 0.2   | 0.6   | 1.3    | 4.1.  | 4.6    |
|        | n         | 40    | 40    | 40     | 37    | 37     |
|        | T         | 1.04  | -1.48 | -3.21  | -4.23 | -2.01  |
| T-test | df        | 78    | 78    | 78     | 72    | 70     |
|        | prob      | 0.301 | 0.144 | 0.002* | 0.000 | 0.048* |

\* =  $P < 0.05$

TABLE 16. COMPARISON OF VEGETATIVE WEIGHTS AT BEGINNING OF SAMPLING FOR THE LEONTODON FLOWERS AND NON-FLOWERS

| $\sqrt{\text{Vegetative Wt.}}$<br>Wk.1 Quarry. |           |        |        | $\sqrt{\text{Veg.Wt.}}$<br>Wk.1 Grass |           |        |             |    |        |  |  |
|--|-----------|--------|--------|---------------------------------------|-----------|--------|-------------|----|--------|--|--|
| Flowers  | $\bar{x}$ | 12.7   | 10.007 | Quarry                                | $\bar{x}$ | 12.7   | Quarry      | x  | 7.5    |  |  |
|  | SD        | 4.12   | 2.73   | Flowers                               | SD        | 4.12   | Non-Flowers | SD | 2.15   |  |  |
|  | SE        | 0.878  | 0.683  |                                       | SE        | 0.878  |             | SE | 0.574  |  |  |
|  | n         | 22     | 16     |                                       | n         | 22     |             | n  | 14     |  |  |
| Non-Flowers                                    | $\bar{x}$ | 7.5    | 7.63   | Grass                                 | $\bar{x}$ | 10.007 | Grass       | x  | 7.63   |  |  |
|  | SD        | 2.15   | 1.8    |                                       | SD        | 2.73   | Non-Flowers | SD | 1.8    |  |  |
|  | SE        | 0.574  | 0.436  | Flowers                               | SE        | 0.683  |             | SE | 0.436  |  |  |
|  | n         | 14     | 17     |                                       | n         | 16     |             | n  | 17     |  |  |
| T-test   | T         | 4.68   | 3.78   |                                       |           | 2.406  |             |    | 0.1403 |  |  |
|  | df        | 34     | 31     |                                       |           | 36     |             |    | 29     |  |  |
|  | P         | 0.001* | 0.001* |                                       |           | 0.05*  |             |    | NS     |  |  |

Comparison of Vegetative Weights of flowers one week before flowering and non-flowers at end of sampling.

|           | Quarry | Grass  |
|-----------|--------|--------|
| $\bar{x}$ | 13.8   | 12.506 |
| SD        | 3.96   | 2.215  |
| SE        | 0.84   | 0.55   |
| n         | 22     | 16     |
| $\bar{x}$ | 11.189 | 11.02  |
| SD        | 3.957  | 2.325  |
| SE        | 1.06   | 0.563  |
| n         | 14     | 17     |
| T         | 1.94   | 0.79   |
| T-test df | 34     | 31     |
| P         | NS     | NS     |

Comparison of Vegetative Weights of early and late flowers.

|                |           |        | If Grass Plants are Included |
|----------------|-----------|--------|------------------------------|
| Quarry Flowers | $\bar{x}$ | 13.35  |                              |
| Wks. 2 & 3     | SD        | 4.08   |                              |
|                | SE        | 1.13   |                              |
|                | n         | 13     |                              |
|                | $\bar{x}$ | 11.718 | 10.623                       |
| Wks. 4 & 5     | SD        | 3.972  | 3.33                         |
|                | SE        | 1.32   | 0.66                         |
|                | n         | 9      | 25                           |
|                | T         | 0.9    | 2.707                        |
| T-test         | df        | 21     | 37                           |
| P              | P         | NS     | 0.05                         |

\* =  $P < 0.05$

TABLE 17. CORRELATION OF  $\sqrt{\text{VEGETATIVE WEIGHT}}$  FOR  
LEONTODON AT BEGINNING OF SAMPLE PERIOD AND  
REPRODUCTIVE WEIGHT AT END OF SAMPLE PERIOD.

QUARRY             $r = .7098$   
                     $t = 4.507$   
                     $df = 21$

$P < .001^*$

GRASS             $r = .5515$   
                     $t = 1.0913$   
                     $df = 15$   
                    NS

TOGETHER         $r = .559$   
                     $t = 4.045$   
                     $df = 37$

$P < .001^*$

## 7 DISCUSSION

### 7.1 Validity of Techniques Employed

The majority of the regressions employed give an expected error range of between 1 5% and 1 30% (see Appendix) using Whittaker and Woodwell's (1968) estimate of relative error ie.

$$\frac{\sqrt{(\sum d^2/n - 1)}}{y} \quad \text{where } d = \text{deviation} \\ y = \text{mean observed weight}$$

This is similar to the values obtained by Hutchinson (1975) using data on Mercurialis perennis. He also found that quadratic regressions gave the greatest predictive accuracy. In this study, however, it was found that the use of quadratics with some data (particularly the Leontodon data) can lead to excessive generation of negative values. This difficulty, which occurs when using polynomials has been explained by Mead (1971). In biological situations, polynomials can give ridiculous values of 'y' the dependent variable for particular values of the independent variables. This occurs at the extremes of the possible range and explains why certain regression formulae predict plant dry weights to be negative. Hence quadratics seem to be of limited value in biological situations where the whole range of possible predicted values is not known.

As a result of this problem, the first and last regressions determined for Leontodon hispidus had to be discarded and the second regression was applied to the field data throughout the season. This has probably slightly increased the error in these predictions at the beginning and end of the season since Hutchings (1975) showed that Mercurialis perennis exhibited changes in dimension and weight relations throughout the season. The extent of these changes is debatable and many workers have ignored them. Kuroiwa (1960) states that his regression was made 34 days after sowing but applies it to estimate plant weights from 0-40 days after sowing. Nevertheless,



the fact that different regressions give better estimates over the season for Plantago lanceolata tends to support Hutchings' conclusions. Moreover, this is undoubtedly the case for reproductive dry weight since scape length in Plantago lanceolata is unimportant at the beginning of the season but becomes the major predictor of reproductive dry weight at the end.

Of the plant dimensions which could feasibly be measured in the time available, plant diameter and number of leaves were found to give the best predictive estimates. Not surprisingly diameter is a common parameter utilised in predictive regressions since diameter squared gives some indication of plant area. It has been applied successfully as part of a regression equation by Whittaker and Woodwell (1968) in assessment of tree and shrub production and by Hutchings (1975) to predict the dry weight of Mercurialis perennis. In the majority of previous studies, however, the plants studied have been distinctly three-dimensional in character so the regression provides a factor to convert volume to weight eg Hutchings use  $hd^2$  where  $h$  = height and  $d$  = diameter. A rosette plant, however can virtually be regarded as two dimensional and empirical measurement of its thickness would be an impractical procedure. Warner (1975) uses a regression based on diameter as an indicator of weight for a rosette plant (Dipsacus foliolosus). This work on Plantago lanceolata and Leontodon hispidus suggests that a possible parameter to indicate the thickness of a rosette plant might be number of leaves, particularly when the rosette lies close to the ground surface.

For plants such as Leontodon and Plantago where the scape is a major component of their reproductive structures, measurement of its length provides an adequate indication of total reproductive weight. However, this relationship may not be so good at the commencement of reproductive resource allocation as has been shown

for Plantago. It might be argued that when reproductive effort is under consideration this parameter ignores the most vital components ie the fruit and seeds. However, if the previous definition of reproductive effort is accepted (ie RE = dry weight of all reproductive organs as a percentage of the total dry weight), the sole use of this parameter is valid.

In addition to errors caused because of changes in dimension and weight relations throughout the season possibly the largest source of error is that attributable to random variability in the material itself (Sprent 1972). Thus, genotype may effect the relationships between morphological dimensions and mass as will environment e.g. an elongate plant with few leaves, growing in a shady environment may have the same biomass as a stocky plant growing in a light environment. This factor is of particular relevance to this study. Although it was found that plants from the two sites did have slightly different dimension and weight relations, the overall error of the predictions was reduced by combining the two populations in computation of the regression. Moreover this also reduced the number of calculations necessary and differences in morphology of the plants from the two sites could be determined from consideration of the data on rosette diameter and number of leaves.

Other sources of error may have been in weighing and measuring observations and in variations in the amount of water vapour present in each plant. Nevertheless, care was taken at all times to minimise this type of error. Evans (1972) gives examples of evidence for increases in respiration rate and consequent reductions in weight increments caused by disturbance of plant tissues. He indicates that if the time intervals between measurements are long it is unlikely that alterations in respiration rate will persist from one time of measurement to the next. As, similar measurements were taken from

each plant it is unlikely that this phenomenon would differentially effect the plants in one group.

Some difficulty was experienced in delimiting root stock tissue from stem stock tissue in Plantago and this may have been a source of error in the dry weight determinations. Finally, some error may have resulted from the transformation of the data (Hutchings 1975). However it was considered preferable to tolerate this slight error which would enable the use of parametric methods of statistical analysis rather than resort to non-parametric methods which are considered to be less efficient (Sokal and Rolf 1969).

More accurate regressions would undoubtedly have been achieved if several of the more discerning parameters were selected and combined in a complicated multiple regression programme. One of the principle aims of the study, however was to provide a quick simple method of assessing plant weight in the field rather than time-consuming destructive sampling. A laborious field measuring programme would have defeated this object. Taking all of these factors into consideration the regressions provided a useful predictive tool with reasonably accurate estimations. Random variability and the error factors mentioned prevent the possibility of making completely accurate predictions of the values of biological variables. Nevertheless in the subsequent analyses mean plant weights are used, and since individual errors in prediction are normally distributed about the true values, these errors will probably cancel themselves out in the determination of a mean weight based on a large enough sample of individuals.

One of the major assumptions of the study was in the method of assessment of reproductive effort. The limitations of the popular method of R.E. determination by using the weight of reproductive parts as a percentage of total weight (Harper and Ogden 1970) which do not consider the physiological costs of producing such structures have

been pointed out (Hirshfield and Tinkle 1975). Nevertheless, no research technique has proved superior for field studies requiring a large sample size (Primack 1979). The alternative method of assessing final reproduction by determining the number of capsules produced per plant, which was attempted here, shows a similar pattern of allocation to that indicated by the traditional method of R.E. determination. Nevertheless the differences between some sets of plants are more significant and this illustrates the need for caution when interpreting R.E. determinations Hickman (1975) suggests that seed allocation is appropriate for assessing the relative contribution of different plants to the next generation whereas reproductive effort (Harper and Ogden 1970) is a measure of energy cost to the parental generation of making certain seed energy contributions. The difficulty here, is in determining which organs are reproductive e.g. the scapes of P. lanceolata and L. hispidus, being photosynthetic, also have a vegetative function but in this study this is considered as being subsidiary to their reproductive function.

The need for careful examination of possible measures of R.E. is also evident when the data on no. of capsules/unit vegetative weight are examined. The quarry plants in the field have by far the greatest value supporting the r - and K - selection paradigm. Seed output can be used as a measure of the relative fecundity of a species but the germinability of the seeds contributes to this fecundity. The study of germinability of the seeds under different conditions of light and dark was intended as a measure of this factor but the results from this experiment were inconclusive

## 7.2 Control of Flowering

The decision to flower or not to flower must be a crucial one. In this study it appears that Leontodon is more capable of governing its population RE than Plantago since Leontodon shows a much larger variation in population RE between the two sites. It is probable that this decision is influenced by the size or nutritional status of the plant. Plants must achieve a certain 'ripeness to flowering' before they are capable of responding to the environmental factors which induce the formation of flowers (Hillman 1962). Species of Plantago are induced to flowering by long days (Snyder 1948) and Primack (1979) suggests that in annual species of Plantago this threshold of the 'ripeness to flowering' seems to have been lowered enough so that the stimulus to flowering produces a response in every individual regardless of every size and age. He proposes that in perennial species selection may have acted to raise the threshold so that only plants in the 'best condition' flower.

In many studies of reproductive allocation eg Stewart (1979) an examination of plant weight and its relation to flowering is impossible because of the method of sampling. The relationship between plant size and the decision to flower is only valid when the same plants have been followed throughout the season. The use of regression techniques enabled this relationship to be studied. In Leontodon hispidus flowering appears to be controlled by plant size at the beginning of the season supporting Stewarts (1979) theory and Werners (1975) findings for Dipsacus fullonum. Not only is the decision to flower governed by plant size but the level of reproductive biomass is positively correlated with the vegetative weight

at the beginning of the season. Hickman (1975) found a negative correlation between reproductive allocation and dry weight in the annual Polygonum cascadenae. Other workers have found that the decision to flower may be influenced by nutrient status (Van Andel and Vera 1977) or the development of a sizeable root biomass (Raynal 1979).

Stewart (1979) found no association between leaf dry weight and flowering when samples were taken simultaneously and suggests that this may be because increase in reproductive biomass is at the expense of growth in vegetative biomass. This response is suggested by the decrease in vegetative weight soon after the onset of flowering shown in the curves for P. lanceolata and L. hispidus. This response is also implied in the percentage allocation diagrams for Senecio vulgaris (Harper and Ogden 1970) and Tussilago farfara (Ogden 1974). The fact that there was no significant difference between the vegetative weights of flowerers one week before flowering and non-flowering at the end of the sampling period whilst there was a difference at the beginning of the season supports this theory (see table 17) Stewart (1979) appears to have been right in saying that weight must be measured before flowering and this might explain why Hickman (1975) found a negative correlation between dry weight and reproductive allocation when he sampled after flowering.

### 7.3 Differences between Sites

Each of the two species shows a different reaction at each site in terms of its reproductive effort. L. hispidus has a significantly higher RE for three of the four sampling occasions when the plant was flowering. This difference was significant for both mean flowering individual RE and mean population RE ie not only did more of the plants flower at the quarry site but also those which did flower allocated

more of their available resources to flowering than at the grassland site. This decrease in reproductive allocation in a more moderate environment concurs with work by Hickman (1975) on Polygonum cascadense. Reproductive allocation was found to decrease significantly along a moisture gradient so allocation was greatest in the successively harsher and more open habitats. Hickman attributes this environmentally cued response to the short term unpredictability of the environments in which the species grows. Whigham (1974) found the RE of Uvularia perfoliata was similarly effected by environmental conditions.

Differences in the level of RE attained by L. hispidus in the earlier sampling periods can be partly attributed to the marked variation in the time of anthesis at the two sites, also noted by Stewart (1979) at Thrislington common and Wingate quarry. Thus the Leontodon plants in the harsher quarry environment where summer drought is likely to be a major mortality factor, flower earlier and devote more resources to sexual reproduction. Law et al (1977) compared populations of Poa annua experiencing either predominantly density-dependent or density-independent regulation. They found that the two populations showed genetically determined life-history differences. Selection under density-independent regulation produced individuals that had a shorter pre-productive period, a higher seed output earlier in life and shorter lives in general. These results are similar to those of Abrahamson and Gadgil (1973) who noted that populations of Solidago from successional less mature sites flowered earlier and had a greater reproductive allocation. Roos and Quinn (1977) found significant differences in the mean dates of the first anthesis of Andropogon which were environmentally induced.

In contrast P. lanceolata plants display no significant differences in either mean flowering individual RE or total population RE between the two sites. Despite a considerable and highly significant depression in vegetative and reproductive dry weights at the quarry site the

levels of flowering individual RE remain constant. Hawthorn and Cavers (1978) find a similar response in Plantago major when density was increased and they interpret this as an adaptation to exploitation of frequently disturbed sites by producing seeds 'at all costs'. Constancy in individual sexual RE under differing conditions has been noted by several workers for annuals eg Harper and Ogden (1972) for Senecio vulgaris, Primack (1979) for annual Plantago spp. and perennials eg Bradbury and Hofstra (1976) for Solidago canadensis, Holler and Abrahamson (1977) for Fragaria virginiana, Ogden (1974) for Tussilago farfara and Raynal (1979) for Hieracium florentinum. Some of these studies have indicated changes in vegetative reproduction under different environmental conditions but this factor was not recorded for Plantago and Leontodon in the field. Measurements of the transplanted greenhouse plants indicated that there were no significant changes in vegetative reproduction between plants from the two sites.

Similarly there are no significant differences in population RE between the two sites although there is a consistent trend towards grassland plants having a larger mean population RE (more plants flowered). Stewart (1979) found a variation in the population RE but at his quarry site (Wingate quarry) the population RE was higher than at the grassland site (Thrislington common).

Nevertheless both flowering individual RE and mean population RE vary in the greenhouse plants and seedlings, although again there is no difference between sites. Mean population and mean flowering individual RE reach approximately 59% in the greenhouse seedlings and plants but only 42% per flowering individual and 19% per member of the population in the field samples. This variation in the number of individuals which attempt to flower accords with Van Andel and



Vera's (1977) findings for Chamaenerion angustifolium. More individuals were stimulated to flower under better soil conditions. With P. lanceolata it appears that the difference in environmental conditions between the grassland and quarry sites is not sufficient to stimulate any differences in RE but the difference in conditions between the field Plantago plants and those grown in the greenhouse is sufficient.

The fact that flowering individual RE and mean population RE are very similar in the greenhouse populations whereas these figures vary in the field populations suggests that any field differences in the populations are phenotypic responses to environmental conditions rather than genetically inherited characteristics. Although there are no differences in RE between sites for P. lanceolata the fact that the size differences of plants in the field disappear in the greenhouse suggests these differences are environmental. The significant differences in the vegetative and reproductive dry weights of plants from the quarry and grassland throughout the sampling period is not found in the seedlings from both sites, grown in the greenhouse. For the first two sample weeks transplanted plants in the greenhouse show significant differences but these become less distinct until at the end of the sampling period the two populations can be regarded as being synonymous. Thus, the effect of external conditions is overcome when the plants are grown in a homogeneous environment. Moreover there is a significant difference between transplanted plants grown in the greenhouse for part of their life and seedlings grown there for their entire life, suggesting that environmental factors which have influenced a perennial plant in one season effect the plant's production in the following season. If so, this tends to raise queries concerning the validity of research based on transplanted plants rather than seeds or seedlings.

Hickman (1975), Roos and Quinn (1977) and Raynal (1979) have found differences in RE to be environmental in origin although Roos and Quinn (1977) did find some evidence of genetic differences. Primack (1978) quotes work in which he found differences in P. lanceolata RE to be both genetically and environmentally determined whereas Gadgil and Solbrig (1972) identified two distinct biotypes in Taraxacum officinale.

Unfortunately, no greenhouse experiments were carried out on L. hispidus, which was the species displaying significant differences in RE between the two sites. However the fact that there is no significant difference between the size of the non-flowerers in the quarry and the grassland (see Table 16) suggests that the differences are environmental. Differences in the mean size between the flowerers are to be expected since the quarry plants are larger. This suggests that the quarry and grassland Leontodon plants are similar in the size that must be attained to initiate flowering. Comparison of the actual levels of RE attained by Leontodon at the end of the sampling period must be treated with caution since the level of RE in the grassland was still steeply rising at the end of the study.

#### 7.4 Succession, Reproductive Effort and r - and K - selection

Plantago and Leontodon have very different responses to the variation in environmental conditions occurring in succession. In the field Plantago has a phenotypically lower weight in the early successional stage with a constant RE at both sites. Leontodon, however has a significantly higher plant weight, flowering individual RE and population RE at the earlier successional site. The difference in behaviour of the two species at Thrislington common might be partly because of differences in the sample site used for each species. These effects, however are likely to be negligible since the vegetation

at both sites was the same density and height and was on similar soil.

Succession does not merely involve a change in one or two environmental factors but is a combination of effects which may operate at varying intensities at different stages. Moreover, the type of succession which has been studied in previous work varies. The conditions which operate under a succession from arable fields to deciduous forest as studied by Newell and Tramer (1978) are presumably very different from those operating in a succession from quarry floor to grassland as considered by Raynal (1977) and in this study. The majority of successions which have been studied are of a secondary nature, that is occurring in a gap in an already existing community. The succession studied here has many of the features of a primary succession (that is one which occurs in a pristine unaltered environment), particularly high stress at the beginning of the succession.

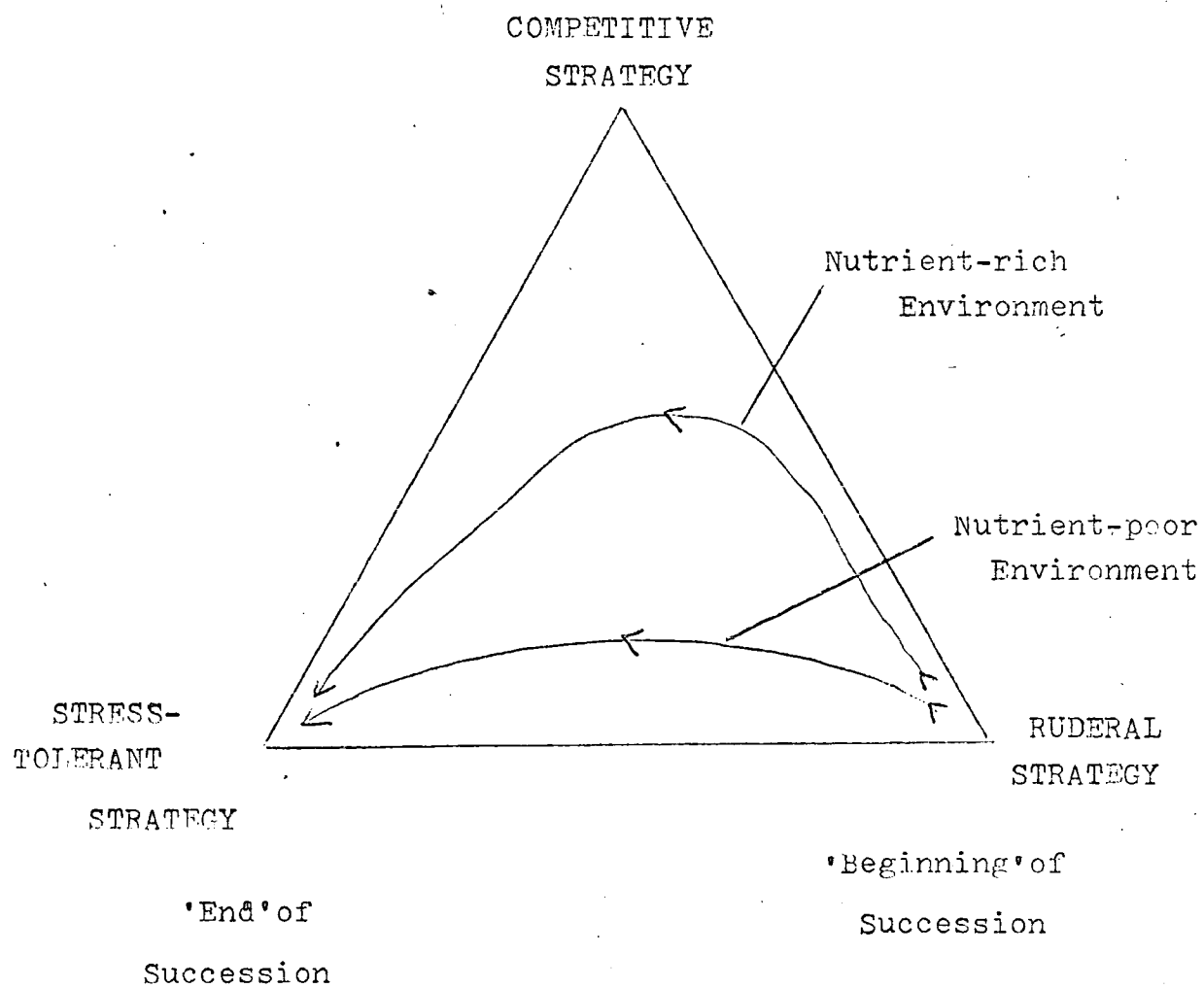
Not only must the variety of different factors involved in succession be taken into account but also the variation in species response. Annuals have been found to have higher RE's than perennials eg Pitelka (1977) and this has been interpreted as an adaptation to their life style and typical habitat. It seems therefore not unreasonable to infer that within each group there may be a range of reproductive strategies. Hence, Leontodon has a strategy adapted to the quarry environment (where it is more common) whereas Plantago is more adapted to the grassland. Each species and in fact biotype may show different responses to changes in the environment and it is inadvisable to infer that other species have similar reactions. Hickman (1977) found a diversity of responses by closely related species along the same environmental gradient and warns against incautious application of proposed general explanations of energy behaviour such as r - and K - selection theory.

Grime (1977) has proposed a model of succession in terms three strategies ie stress tolerant species, competitors and ruderals. Since succession begins with a disturbance ruderals will tend to predominate (ruderals, characteristically have high RE's) As succession proceeds competitive plants will become more successful until in the climax community stress - tolerant individuals will be most prevalent. The exact nature of the succession however, will depend on the nature of the substrate on (see Fig. 17). Thus on a poor substrate such as the quarry floor some ruderals may have to be adapted to resist the adverse conditions. High RE is a good adaption to frequent disturbance but not stress. Vegetative and Reproductive dry weights are lower in the grassland.

Leontodon is a slow growing ( $R_{MAX} = 0.89$  see Grime and Hunt 1975) stress-tolerator and cannot tolerate competition at closed sites such as the grassland. The low RE values obtained for Leontodon here are probably an adaptation related to the high density dependent mortality. At high total vegetation cover more energy will be proportionately allocated to support tissues which maximise a plant's competitive ability for light. Abrahamson and Gadgil (1973) and Gaines et al (1974) found a direct correlation stem allocation and total stand cover. The relative elongation of the grassland Leontodon leaves is shown in table 2. These typical responses to density in the form of the dry weight of plants parts have been well documented eg by Palmblad (1968) as have leaf area responses to shade (Grime 1977). A slow growth rate is typical of stress-tolerators and the plant rosette is well adapted to reduce water loss. Thus Leontodon is physiologically and morphologically better adapted to the quarry site.

Plantago lanceolata is a competitive ruderal ( $R_{MAX} = 1.7$ ) typically of productive and relatively open sites. It has many

FIG. 17 GRIME'S DIAGRAMMATIC REPRESENTATION OF SUCCESSION  
AT VARIOUS NUTRIENT LEVELS



features of an annual eg a high growth rate and in particular a tendency to maintain its RE under adverse conditions. This factor accounts for the lack of difference in RE between the two sites although it clearly does better at the grassland site. Reproductive and vegetative dry weights are higher here and it seems unable to attain the same levels of biomass in the stressful quarry site. Hence the different response of each species in terms of their reproductive effort at each site can be explained in terms of the individual species strategy and the nature of the succession under consideration.

## 8. SUMMARY

1. Regression techniques were found to be useful in predicting mean weights of populations. However, where very accurate results are required the measurement of suitable parameters in the field is too time-consuming and the applicability of such techniques is limited. The relationship between the plant dimensions of Leontodon hispidus and Plantago lanceolata did change throughout the season so more than one regression analysis was necessary.
2. The method of assessing RE was by determining the dry weight of the reproductive parts of the plant as a percentage of its total weight. Two alternative methods of assessing reproductive allocation by determining the number of seed capsules/plant and seed capsules/unit vegetative weight were tried. These methods gave slightly different results and illustrate the need for caution when choosing a suitable method of assessing RE.
3. A greater number of individuals of L. hispidus flowered at the quarry site, that is this site had a larger population RE. The vegetative weight of the plant at the beginning of the season was found to be related to this decision to flower. The larger the plant was at the beginning of the season the more likely it was to flower. Moreover the level of vegetative weight at the beginning of the season was found to be directly related to the level of reproductive dry weight achieved. There was a decline in vegetative weight immediately after flowering in both species.
4. Reproductive effort of P. lanceolata was similar at both sites in the field however, RE of L. hispidus was greatest, (and the date of first anthesis was earlier) at the early successional quarry site. Although the level of RE attained by P. lanceolata in the greenhouse was higher there was again no difference between plants from each site.

5. The two species did differ in biomass and morphology at each site. L. hispidus produced larger plants with longer, wider leaves at the quarry site. P. lanceolata produced larger plants at the grassland site. These morphological differences disappeared when P. lanceolata was grown in a homogeneous environment implying that they were phenotypic responses to environmental variables. Since quarry and grassland L. hispidus plants are similar in the size that must be reached to initiate flowering, this suggests RE and morphological differences in this species are also environmentally cued.

6. The different response of each species at each site in terms of their reproductive allocation is explained in terms of their individual species strategy, the nature of succession, and the special characteristics of the particular succession under consideration.



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Appendix I    SCAPE LENGTHS FOR LEONTODON HISPIDUS  
AND PLANTAGO LANCEOLATA

APPENDIX. PLANTAGO TOTAL LENGTH SCAPES. FLOWERING POPULATION

| <u>FIELD PLANTAGO</u> |           |        |        |        |        |        |
|-----------------------|-----------|--------|--------|--------|--------|--------|
| Week                  |           | Wk.1   | Wk.2   | Wk.3   | Wk.4   | Wk.5   |
| GRASS                 | $\bar{x}$ | 19.3   | 371.0  | 529.7  | 597.1  | 680.4  |
|                       | SD        | 13.3   | 252.6  | 337.9  | 403.2  | 465.1  |
|                       | SE        | 2.3    | 44.66  | 61.7   | 82.3   | 94.9   |
|                       | n         | 34     | 32     | 30     | 24     | 24     |
| QUARRY                | $\bar{x}$ | 11.6   | 254.0  | 361.6  | 389.6  | 413.5  |
|                       | SD        | 8.1    | 168.6  | 227.9  | 281.1  | 283.5  |
|                       | SE        | 1.4    | 30.3   | 40.3   | 52.2   | 53.6   |
|                       | n         | 31     | 31     | 32     | 29     | 28     |
| T-test                | T         | 2.75   | 2.15   | 2.31   | 2.2    | 2.54   |
|                       | df        | 63     | 61     | 60     | 51     | 50     |
|                       | prob      | 0.008* | 0.035* | 0.024* | 0.032* | 0.014* |

| <u>GREENHOUSE PLANTS</u> |           |       |       |        |        |        |
|--------------------------|-----------|-------|-------|--------|--------|--------|
| GRASS                    | $\bar{x}$ | 30.1  | 600.1 | 2011.3 | 4065.8 | 4307.9 |
|                          | SD        | 20.9  | 469.9 | 865.6  | 1814.1 | 1892.5 |
|                          | SE        | 4.0   | 80.6  | 138.6  | 286.8  | 299.2  |
|                          | n         | 27    | 34    | 39     | 40     | 40     |
| QUARRY                   | $\bar{x}$ | 31.6  | 716.9 | 1975.2 | 4595.2 | 5009.0 |
|                          | SD        | 23.5  | 633.3 | 1057.9 | 1479.9 | 1556.7 |
|                          | SE        | 4.2   | 102.7 | 171.6  | 243.3  | 252.5  |
|                          | n         | 32    | 38    | 38     | 37     | 38     |
| T-test                   | T         | -0.27 | -0.88 | 0.16   | -1.40  | -1.78  |
|                          | df        | 57    | 70    | 75     | 75     | 76     |
|                          | prob      | 0.792 | 0.382 | 0.870  | 0.165  | 0.079  |

| <u>GREENHOUSE SEEDLINGS</u> |           |       |        |        |        |        |
|-----------------------------|-----------|-------|--------|--------|--------|--------|
| GRASS                       | $\bar{x}$ | 25.3  | 1341.1 | 4730.5 | 5885.1 | 5926.3 |
|                             | SD        | 13.9  | 867.9  | 1677.0 | 2134.9 | 2222.8 |
|                             | SE        | 2.4   | 142.7  | 275.7  | 346.3  | 360.6  |
|                             | n         | 33    | 37     | 37     | 38     | 38     |
| QUARRY                      | $\bar{x}$ | 18.9  | 1125.6 | 4040.8 | 5838.6 | 5880.9 |
|                             | SD        | 14.6  | 863.0  | 1977.3 | 2881.9 | 2872.5 |
|                             | SE        | 2.5   | 138.2  | 315.8  | 355.7  | 459.9  |
|                             | n         | 35    | 39     | 40     | 40     | 39     |
| T-test                      | T         | 1.85  | 1.08   | 1.63   | 0.08   | 0.08   |
|                             | df        | 66    | 74     | 75     | 76     | 75     |
|                             | prob      | 0.069 | 0.282  | 0.106  | 0.936  | 0.939  |

\* =  $P < 0.05$

Wk.1 = Mean spike length per plant



APPENDIX. PLANTAGO TOTAL LENGTH SCALES.\* TOTAL POPULATION

| <u>FIELD PLANTAGO</u> |           |        |        |        |       |        |
|-----------------------|-----------|--------|--------|--------|-------|--------|
| Week                  |           | Wk.1   | Wk.2   | Wk.3   | Wk.4  | Wk.5   |
| GRASS                 | $\bar{x}$ | 16.4   | 320.9  | 454.1  | 462.3 | 526.8  |
|                       | SD        | 14.1   | 267.4  | 364.4  | 434.8 | 499.4  |
|                       | SE        | 2.2    | 43.9   | 61.6   | 78.1  | 89.7   |
|                       | n         | 40     | 37     | 35     | 31    | 31     |
| QUARRY                | $\bar{x}$ | 9.1    | 201.9  | 289.3  | 297.3 | 296.9  |
|                       | SD        | 8.6    | 182.3  | 250.5  | 296.6 | 304.4  |
|                       | SE        | 1.4    | 29.2   | 39.6   | 48.1  | 48.7   |
|                       | n         | 40     | 39     | 40     | 38    | 39     |
| T-test                | T         | 2.81   | 2.28   | 2.31   | 1.87  | 2.38   |
|                       | df        | 78     | 74     | 73     | 67    | 68     |
|                       | prob      | 0.006* | 0.026* | 0.024* | 0.066 | 0.020* |

| <u>GREENHOUSE PLANTS</u> |           |       |       |        |        |        |
|--------------------------|-----------|-------|-------|--------|--------|--------|
| GRASS                    | $\bar{x}$ | 20.3  | 510.1 | 1960.9 | 4065.8 | 4307.9 |
|                          | SD        | 22.2  | 483.7 | 911.7  | 1814.1 | 1892.5 |
|                          | SE        | 3.5   | 76.4  | 144.2  | 286.8  | 299.2  |
|                          | n         | 40    | 40    | 40     | 40     | 40     |
| QUARRY                   | $\bar{x}$ | 25.3  | 681.1 | 1924.6 | 4474.3 | 4880.6 |
|                          | SD        | 24.6  | 636.8 | 1090.8 | 1639.1 | 1732.9 |
|                          | SE        | 3.9   | 100.7 | 174.7  | 265.9  | 277.5  |
|                          | n         | 40    | 40    | 39     | 38     | 39     |
| T-test                   | T         | -0.95 | -1.35 | 0.16   | -1.04  | -1.4   |
|                          | df        | 78    | 78    | 77     | 76     | 77     |
|                          | prob      | 0.343 | 0.180 | 0.872  | 0.301  | 0.165  |

| <u>GREENHOUSE SEEDLINGS</u> |           |       |        |        |        |        |
|-----------------------------|-----------|-------|--------|--------|--------|--------|
| GRASS                       | $\bar{x}$ | 20.9  | 1272.3 | 4606.0 | 5885.1 | 5926.3 |
|                             | SD        | 15.9  | 896.3  | 1823.5 | 2134.9 | 2222.8 |
|                             | SE        | 2.5   | 143.5  | 295.8  | 346.3  | 360.6  |
|                             | n         | 40    | 39     | 38     | 38     | 38     |
| QUARRY                      | $\bar{x}$ | 16.5  | 1097.5 | 4040.8 | 5838.6 | 5880.9 |
|                             | SD        | 15.0  | 870.3  | 1997.3 | 2881.9 | 2872.5 |
|                             | SE        | 2.3   | 137.6  | 315.8  | 455.7  | 459.9  |
|                             | n         | 40    | 40     | 40     | 40     | 39     |
| T-test                      | T         | 1.25  | 0.88   | 1.3    | 0.08   | 0.08   |
|                             | df        | 78    | 77     | 76     | 76     | 75     |
|                             | prob      | 0.214 | 0.382  | 0.196  | 0.936  | 0.939  |

\* Wk.I= Mean Spike length per plant

APPENDIX. LEONTODON HISPIDUS.

| <u>TOTAL LENGTH SCALES.</u> |           | <u>FLOWERING POPULATION</u> |       |        |        |        |
|-----------------------------|-----------|-----------------------------|-------|--------|--------|--------|
| Week                        |           | Wk.1                        | Wk.2  | Wk.3   | Wk.4   | Wk.5   |
| GRASS                       | $\bar{x}$ | 0                           | 0     | 0      | 34.5   | 105.4  |
|                             | SD        | 0                           | 0     | 0      | 31.5   | 89.5   |
|                             | SE        | 0                           | 0     | 0      | 15.7   | 21.7   |
|                             | n         | 0                           | 0     | 0      | 4      | 17     |
| QUARRY                      | $\bar{x}$ | 0                           | 28.2  | 71.9   | 240.2  | 319.1  |
|                             | SD        | 0                           | 67.8  | 125.4  | 175.1  | 232.9  |
|                             | SE        | 0                           | 21.5  | 32.4   | 42.5   | 49.7   |
|                             | n         | 0                           | 10    | 15     | 17     | 22     |
| T-test                      | T         | 0                           | -1.31 | -2.22  | -2.3   | -3.58  |
|                             | df        | 0                           | 9     | 14     | 19     | 37     |
|                             | prob      | 1.0                         | 0.221 | 0.0440 | 0.033* | 0.001* |

| <u>TOTAL LENGTH SCALES.</u> |           | <u>TOTAL POPULATION</u> |       |       |       |       |
|-----------------------------|-----------|-------------------------|-------|-------|-------|-------|
| Week                        |           | Wk.1                    | Wk.2  | Wk.3  | Wk.4  | Wk.5  |
| GRASS                       | $\bar{x}$ | 0                       | 0.0   | 0.0   | 3.7   | 51.2  |
|                             | SD        | 0                       | 0.0   | 0     | 14.1  | 81.4  |
|                             | SE        | 0                       | 0.0   | 0     | 2.3   | 13.8  |
|                             | n         | 40                      | 40    | 40    | 37    | 35    |
| QUARRY                      | $\bar{x}$ | 0                       | 7.1   | 26.9  | 110.4 | 189.8 |
|                             | SD        | 0                       | 34.9  | 83.0  | 168.4 | 238.5 |
|                             | SE        | 0                       | 5.5   | 13.1  | 27.6  | 39.2  |
|                             | n         | 40                      | 40    | 40    | 37    | 37    |
| T-test                      | T         | 0                       | -1.28 | -2.05 | -3.84 | -3.26 |
|                             | df        | 78                      | 78    | 78    | 72    | 70    |
|                             | prob      | 1.0                     | 0.205 | 0.043 | 0.000 | 0.002 |

\* =  $P < 0.05$

APPENDIX 2 SCATTERGRAMS FOR REGRESSIONS

SEC REGRES SCATS

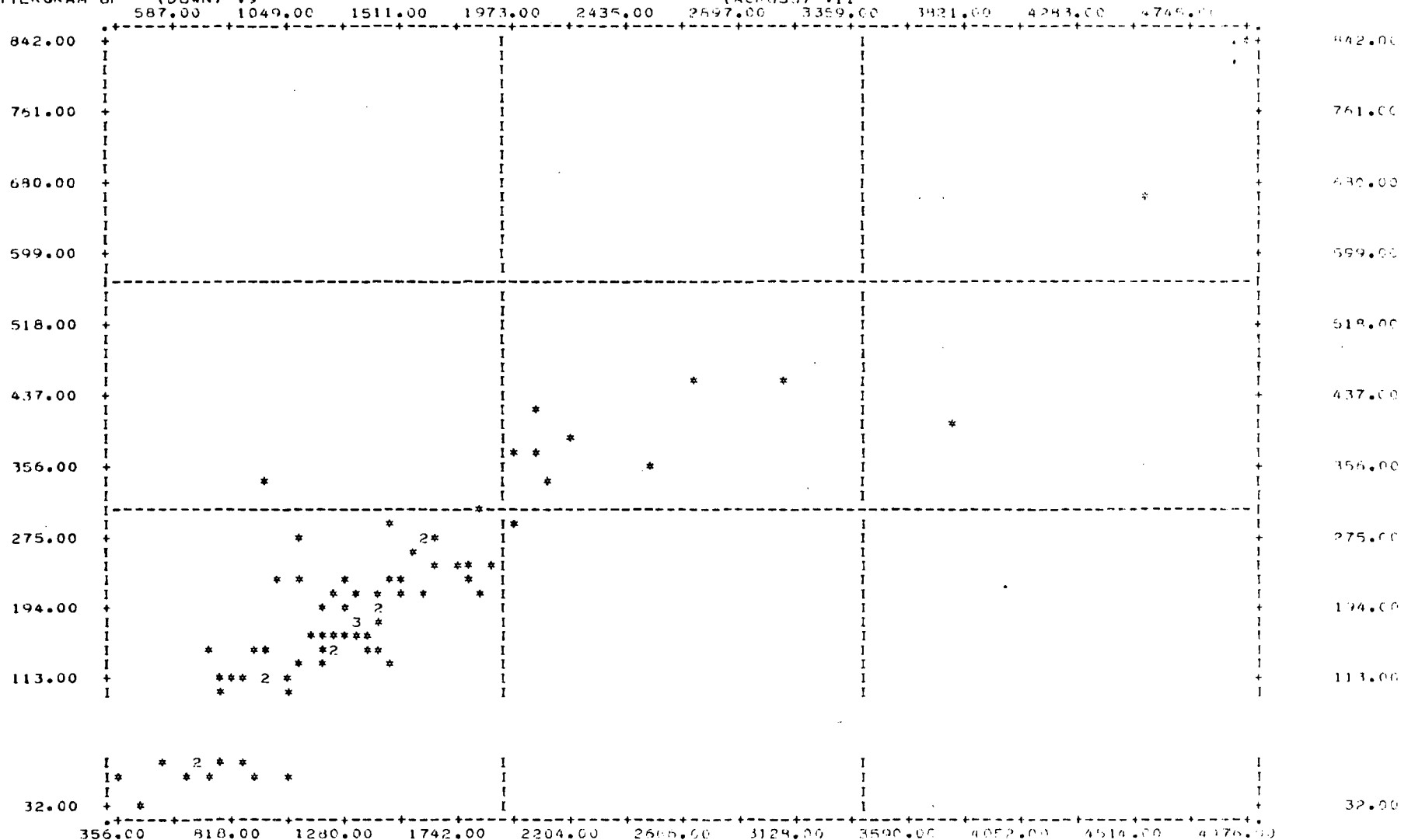
Vegetative Dry Weight with N.x D.  
Leontodon hispidus

09/18/79

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FILE NONAME (CREATION DATE = 09/18/79)  
SCATTERGRAM OF (DOWN) V9

(ACROSS) VII



SEC REGRES SCATS

09/18/79

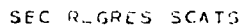
PAGE 13

STATISTICS..

CORRELATION (R)- 0.92219 R SQUARED - 0.85044 SIGNIFICANCE - 0.00001

STD ERR OF EST - 51.11822 INTERCEPT (A) - -14.47573 SLOPE (B) - 0.11187

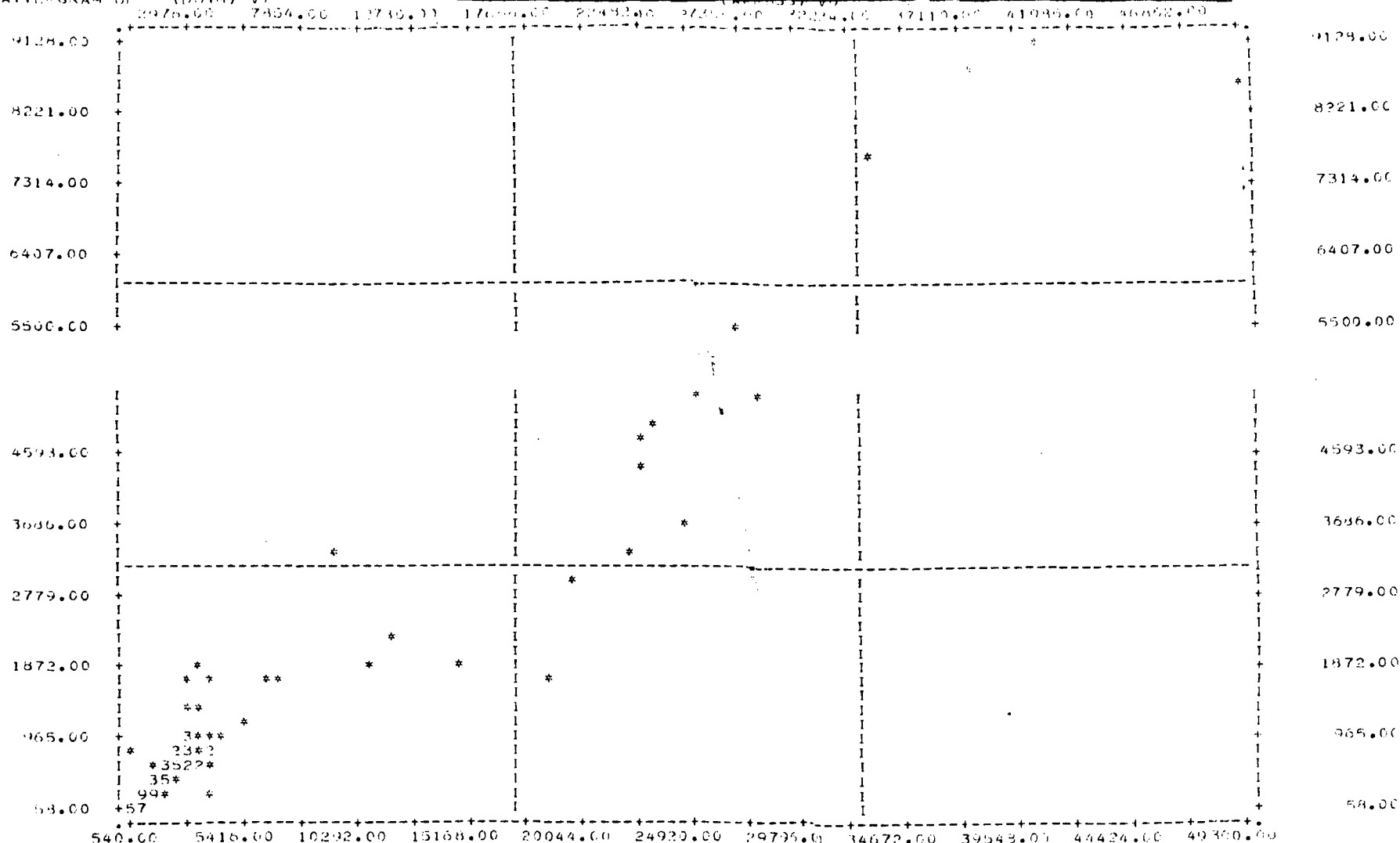
THE REGRESSION LINE CUTS THE MARGINS OF THE PLOT AT  
A VALUE OF 40.24322 ON THE LEFT MARGIN



PAGE 27

|   |          |                   |         |                  |         |
|---|----------|-------------------|---------|------------------|---------|
| CORRELATION (R) =                                   | 0.98991  | R SQUARED =       | 0.94073 | SIGNIFICANCE =   | 0.00001 |
| STD ERR OF EST =                                    | 22.34797 | INTERCEPT (A) =   | 1.31637 | SLOPE (B) =      | 0.76623 |
| THE REGRESSION LINE CUTS THE MARGINS OF THE PLOT AT |          |                   |         |                  |         |
| A VALUE OF 2.03259 ON THE LEFT MARGIN               |          |                   |         |                  |         |
| A VALUE OF 415.84424 ON THE RIGHT MARGIN            |          |                   |         |                  |         |
| PLOTTED VALUES =                                    | 32       | EXCLUDED VALUES = | 0       | MISSING VALUES = | 48      |

\*\*\*\*\* IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.



THIRD REGRES SCATS

07/19/79

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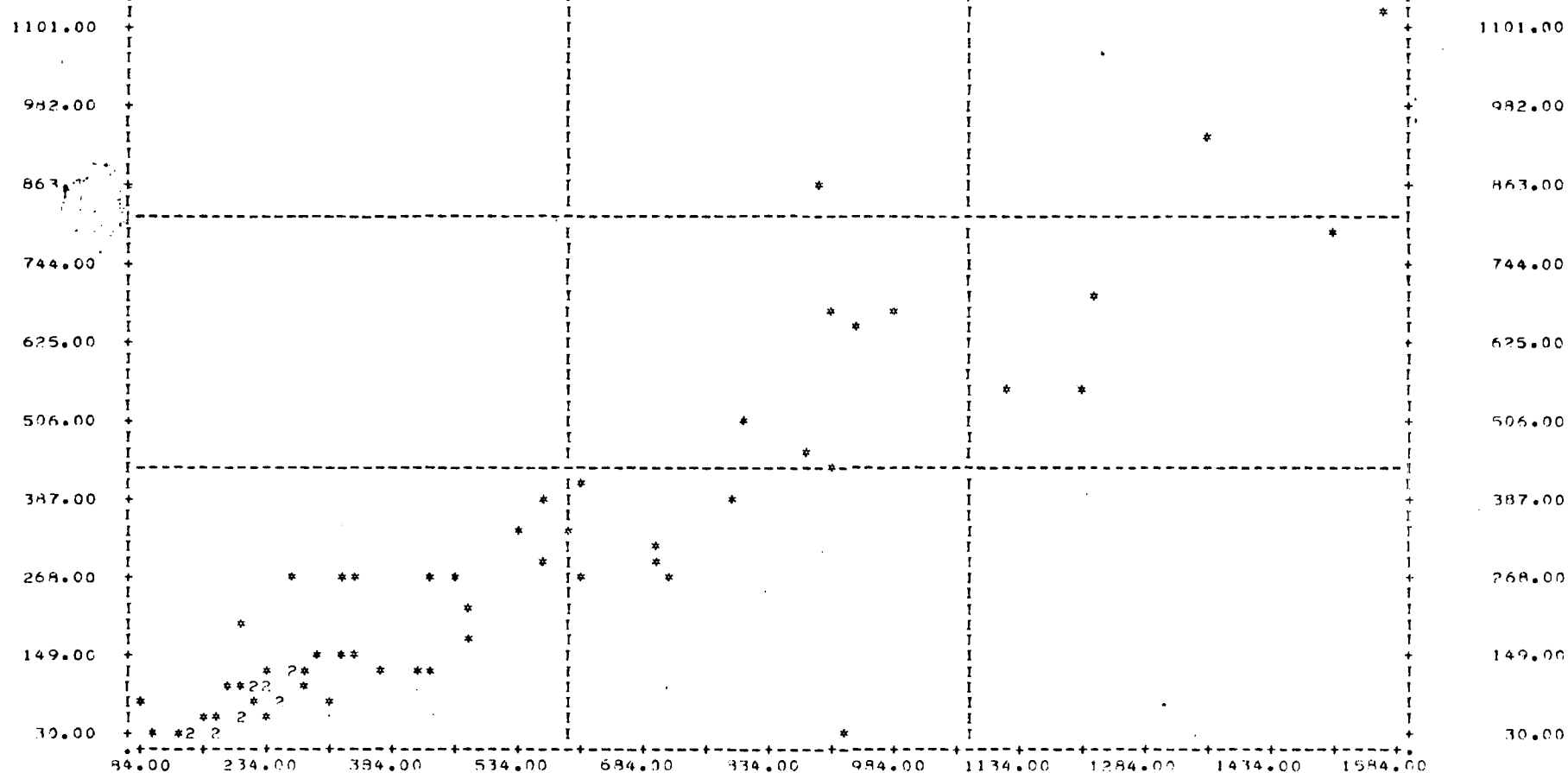
STATISTICS..

|   |           |                  |   |          |                  |   |         |
|---|-----------|------------------|---|----------|------------------|---|---------|
| CORRELATION (R)-                                    | 0.97007   | R SQUARED        | - | 0.94104  | SIGNIFICANCE     | - | 0.00001 |
| STD ERR OF EST -                                    | 483.01409 | INTERCEPT (A) -  |   | 98.76514 | SLOPE (B)        | - | 0.19407 |
| THE REGRESSION LINE CUTS THE MARGINS OF THE PLOT AT |           |                  |   |          |                  |   |         |
| A VALUE OF 203.54218 ON THE LEFT MARGIN             |           |                  |   |          |                  |   |         |
| A VALUE OF 47469.76563 ON THE TOP MARGIN            |           |                  |   |          |                  |   |         |
| PLOTTED VALUES -                                    | 101       | EXCLUDED VALUES- |   |          | MISSING VALUES - |   | 2       |

\*\*\*\*\* IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.

# Reproductive Weight with Total Length Of Scapes

Plantago lanceolata



SEC REGRES SCATS

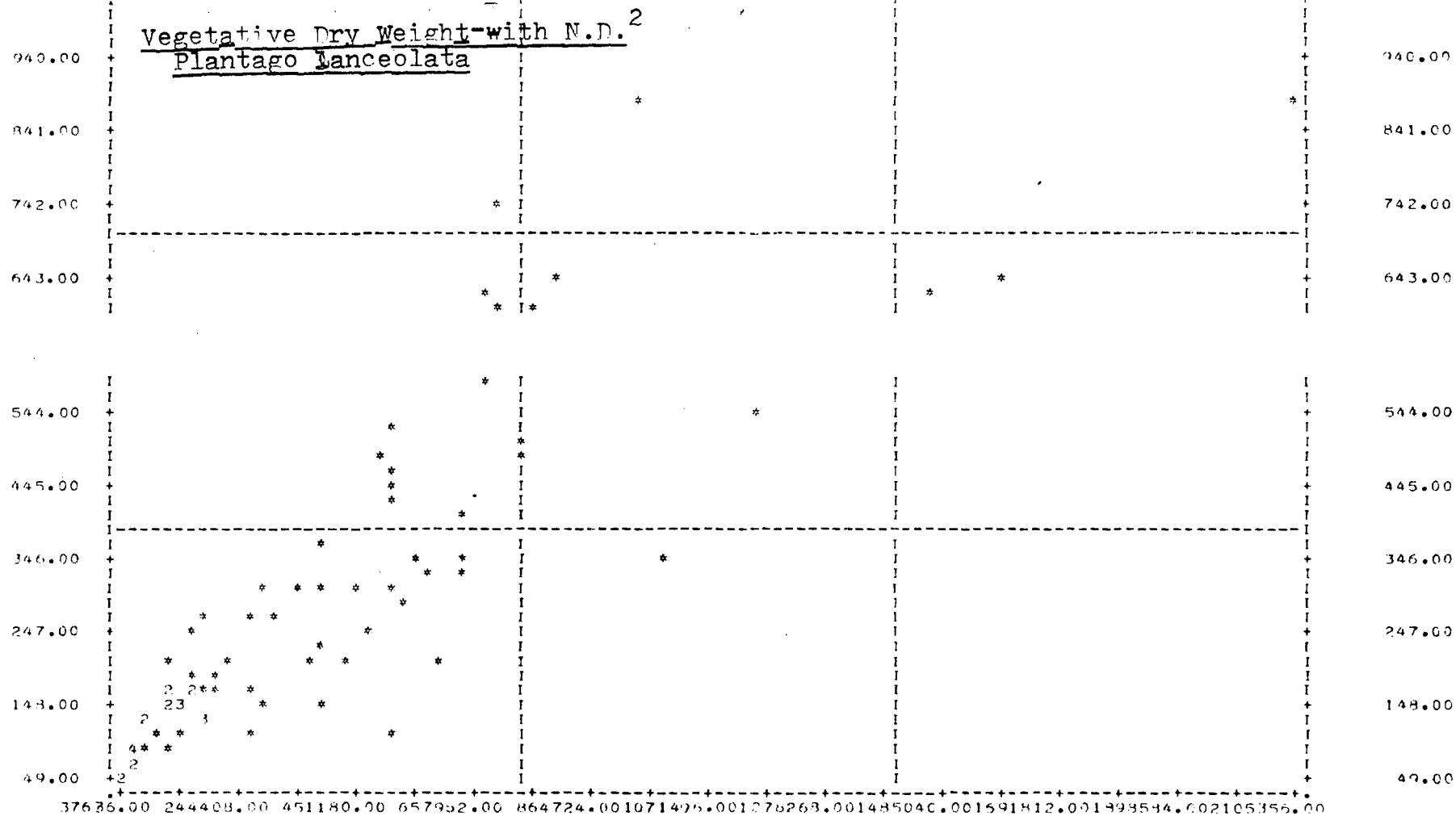
09/12/79

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STATISTICS..

|   |           |                  |   |                  |              |   |         |
|---|-----------|------------------|---|------------------|--------------|---|---------|
| CORRELATION (R)-                                    | 0.90639   | R SQUARED        | - | 0.82154          | SIGNIFICANCE | - | 0.00001 |
| STD ERR OF EST -                                    | 116.90988 | INTERCEPT (A) -  | - | -59.92900        | SLOPE (B)    | - | 0.65728 |
| THE REGRESSION LINE CUTS THE MARGINS OF THE PLOT AT |           |                  |   |                  |              |   |         |
| A VALUE OF 100.45804 ON THE BOTTOM MARGIN           |           |                  |   |                  |              |   |         |
| A VALUE OF 931.30151 ON THE RIGHT MARGIN            |           |                  |   |                  |              |   |         |
| PLOTTED VALUES -                                    | 66        | EXCLUDED VALUES- | 0 | MISSING VALUES - | 14           |   |         |

\*\*\*\*\* IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.



SEC REGRES SCATS

02/19/79

PAGE

4

STATISTICS..

|   |           |                   |   |                  |              |   |         |
|---|-----------|-------------------|---|------------------|--------------|---|---------|
| CORRELATION (R) -                                   | 0.86241   | R SQUARED         | - | 0.75538          | SIGNIFICANCE | - | 0.00001 |
| STD ERR OF EST -                                    | 119.49759 | INTERCEPT (A) -   |   | 95.39337         | SLOPE (B)    | - | 0.00049 |
| THE REGRESSION LINE CUTS THE MARGINS OF THE PLOT AT |           |                   |   |                  |              |   |         |
| A VALUE OF 117.76120 ON THE LEFT MARGIN             |           |                   |   |                  |              |   |         |
| A VALUE OF 1974035.00000 ON THE TOP MARGIN          |           |                   |   |                  |              |   |         |
| PLOTTED VALUES -                                    | 90        | EXCLUDED VALUES - | 0 | MISSING VALUES - | 0            |   |         |

\*\*\*\*\* IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.

SEC REGRES SCATS

02/19/79

PAGE

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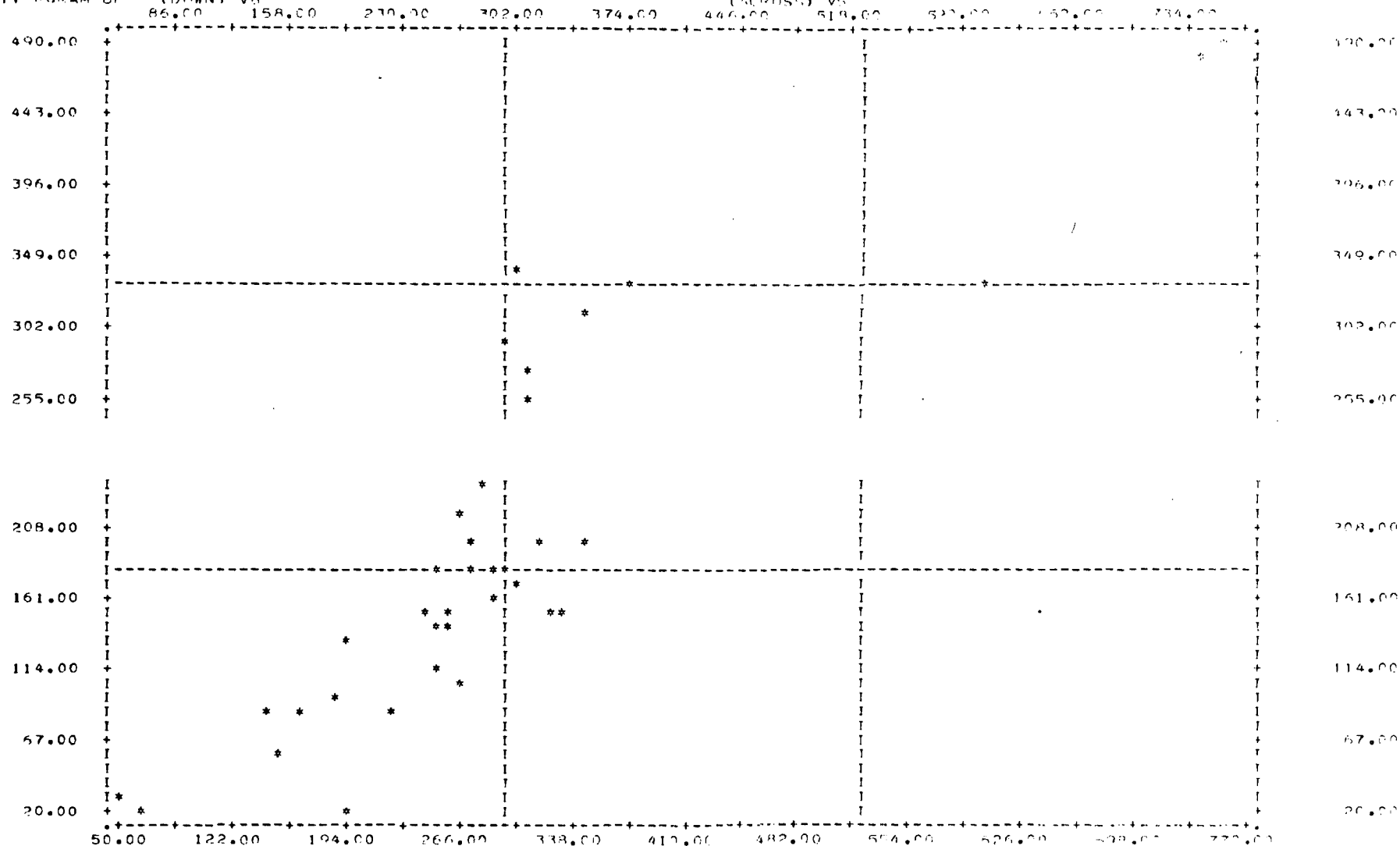
# THIRD REGRES SCATS Reproductive Dry Weight with Total Length of Scapes

FILE NONAME (CREATION DATE = 02/14/79)  
SCATTERGRAM OF (DOWN) VR

Leontodon hispidus

02/14/79

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THIRD REGRES SCATS

02/14/79

PAGE 72

## STATISTICS..

|                  |          |               |   |           |              |   |         |
|------------------|----------|---------------|---|-----------|--------------|---|---------|
| CORRELATION (R)- | 0.88265  | R SQUARED     | - | 0.77907   | SIGNIFICANCE | - | 0.00001 |
| STD ERR OF EST - | 53.08261 | INTERCEPT (A) | - | -12.52409 | SLOPE (B)    | - | 0.68362 |

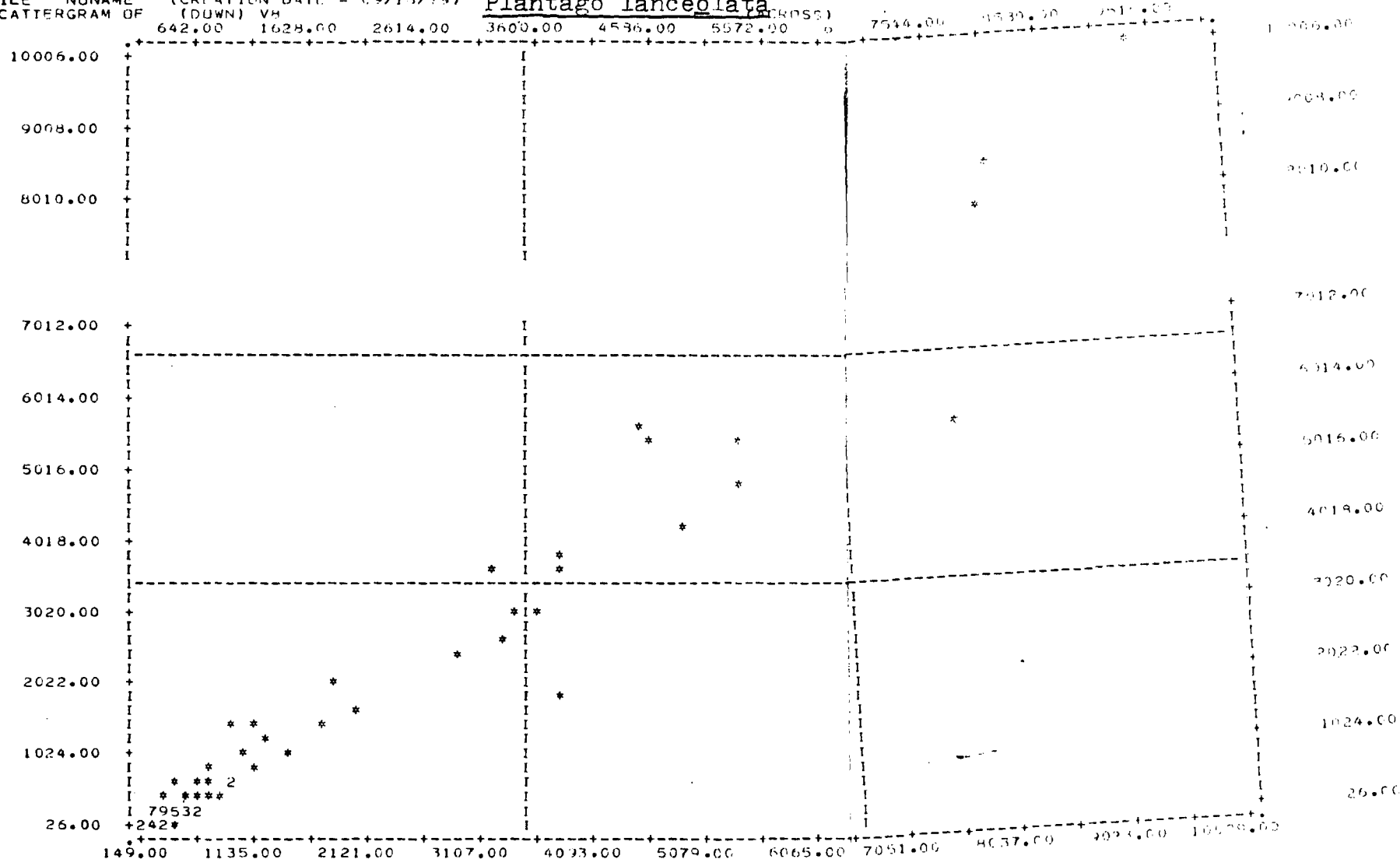
THE REGRESSION LINE CUTS THE MARGINS OF THE PLOT AT  
A VALUE OF 21.85696 ON THE LEFT MARGIN  
A VALUE OF 748.84082 ON THE TOP MARGIN

PLOTTED VALUES - 37 EXCLUDED VALUES -

FILE NUNAME (CREATION DATE = 09/18/79)  
SCATTERGRAM OF (DOWN) VH

Plantago lanceolata

KRO551



THIRD REGRES SCATS

09/18/79

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## STATISTICS..

CORRELATION (R)- 0.98205 R SQUARED - 0.96442  
STD ERR OF EST - 424.97148 INTERCEPT (A) - -159.44195

SIGNIFICANCE - 0.00001  
SLOPE (B) - 0.99643

THE REGRESSION LINE CUTS THE MARGINS OF THE PLOT AT  
A VALUE OF -10.97332 ON THE LEFT MARGIN  
A VALUE OF 9813.86328 ON THE RIGHT MARGIN

PLOTTED VALUES - 73

EXCLUDED VALUES -

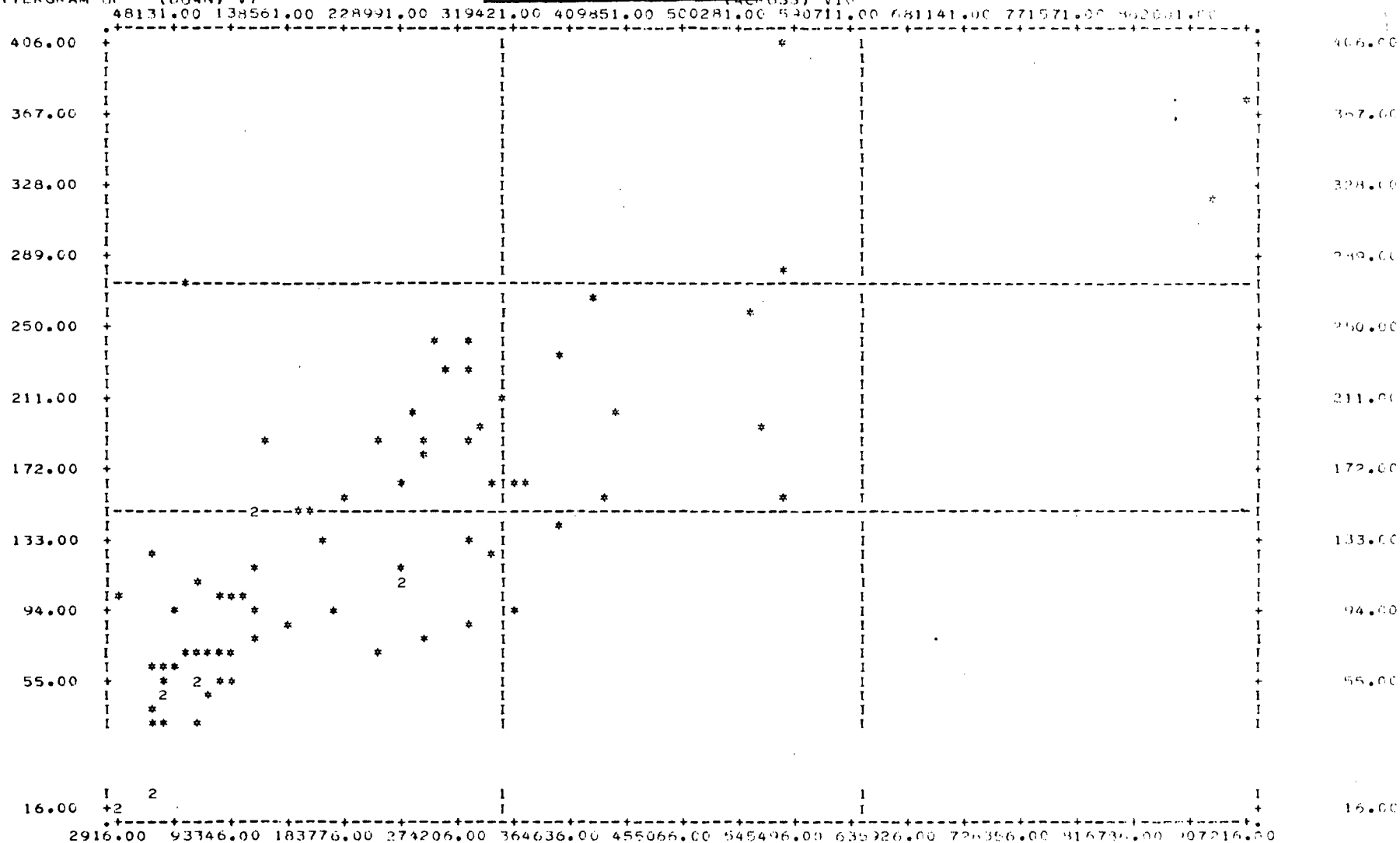
MISSING VALUES -

FILE NONAME (CREATION DATE = 09/19/79)

Leontodon hispidus

SCATTERGRAM OF (DOWN) V7

(ACROSS) V10



## STATISTICS..

|                  |          |                 |          |                |         |
|------------------|----------|-----------------|----------|----------------|---------|
| CORRELATION (R)- | 0.79794  | R SQUARED -     | 0.63671  | SIGNIFICANCE - | 0.00001 |
| STD ERR OF EST - | 50.11831 | INTERCEPT (A) - | 58.75476 | SLOPE (B) -    | 0.00047 |

THE REGRESSION LINE CUTS THE MARGINS OF THE PLOT AT  
 A VALUE OF 59.82291 ON THE LEFT MARGIN  
 A VALUE OF 391.07593 ON THE RIGHT MARGIN

EXCLUDED VALUES

EXCLUDED VALUES

EXCLUDED VALUES

EXCLUDED VALUES

APPENDIX 3 ESTIMATES OF RELATIVE ERROR FOR REGRESSIONS USED

| Regression              | Relative Error % |
|-------------------------|------------------|
| First <u>Plantago</u>   |                  |
| Vegetative              | 5.45             |
| Second <u>Plantago</u>  |                  |
| Vegetative              | 13.35            |
| Third <u>Plantago</u>   |                  |
| Vegetative              | 48.06            |
| <u>First Plantago</u>   |                  |
| Reproductive            | 1.21             |
| Second <u>Plantago</u>  |                  |
| Reproductive            | 14.27            |
| <u>Third Plantago</u>   |                  |
| Reproductive            | 40.6             |
| Second <u>Leontodon</u> |                  |
| Vegetative              | 5.7              |
| Second <u>Leontodon</u> |                  |
| Reproductive            | 3.9              |